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Dam Failure Inundation Map Project

Principal Investigator

Dr. Carl Johnson

Science & Technology International®

Co-Investigator

Dr. Jené Michaud

University of Hawaii at Hilo

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Dr. Carl Johnson, Judy Iokepa, Jill Dahlman, Science & Technology International
Dr. Jene Michaud, University of Hawaii, Hilo

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Science & Technology International Inc.
Grosvenor Center Makai Tower, 733 Bishop Street, Suite #3100
Honolulu, HI 96813-40228. PERFORMING ORGANIZATION
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At the end of the first year, we remain on schedule. Property owners were identified and contacted for land access purposes. A prototype software package has been completed and was demonstrated to the Division of Land and Natural Resources (DLNR), National Weather Service (NWS) and Pacific Disaster Center (PDC). A field crew gathered data and surveyed the areas surrounding two dams in Waimea. (A field report is included in the annual report.) Data sensitivity analysis was initiated and completed. A user's manual has been completed. Beta testing of the software was initiated, but not completed. The initial TMK and property owner data collection for the additional test sites on Oahu and Kauai have been initiated.

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Annual Summary

The year—one objective of the project was to develop and implement a suite of procedures and easy-to-use modeling tools that can be used to facilitate the assessment of dam break hazards in the State of Hawaii. This objective has been accomplished, and we have conducted a prototype dam break assessment at the Waikoloa Reservoir on the Island of Hawai'i.

Major accomplishments during the past year include:

1. Identifying procedures to be used;
2. Developing a program that transforms the dam break model's one-dimensional output to a two-dimensional flood depth map;
3. Creating an easy to use interface that integrates existing models in a manner that is simpler for the user;
4. Collecting detailed, ground-based, topographic data for the test site; and
5. Utilizing the above products to analyze dam break hazards for Waikoloa test case.

These accomplishments will be discussed in detail in the following report. It is important to note that additional accomplishments include the completion of a beta release user's guide and an initial data sensitivity report. Together they represent the tools required to carry out application of this technology to additional sites around the state in Year-two.

Annual Summary by Quarters

FIRST QUARTER SUMMARY

- ❖ Dr. Michaud performed the evaluation of the FLDWAV Model and documentation.
- ❖ A survey of commercial products that integrate graphical interfaces to both the FLDWAV and HEC models was completed. We have been able to shorten the development process by incorporating features of these products.
- ❖ Technical & program evaluation of the model input, output and operating functions were reviewed for design requirements. Background research on the operational issues of running the FLDWAV Model (Fortran) under various operating systems and the interoperability of integrating a database with the model inputs and outputs was initiated.
- ❖ Dr. Michaud and Dr. Johnson met with the PDC regarding their platform requirements. Meetings were set for the beginning of the second quarter to meet with the NWS and the State DLNR, to discuss their software platforms and capabilities for incorporation into the overall design and implementation of the model interface. Final design and implementation of the integrated model will be made after closer observation of PDC, NWS and DLNR computer networks (i.e. platform, operating system, and existing software).

SECOND QUARTER SUMMARY

- ❖ Dr. Michaud and Judy Iokepa met with operational personnel at Division of Land and Natural Resources (DLNR) as well as scientists and managers at NWS, to assess user capabilities and to prioritize field areas for initial analysis. Two dams were targeted as being particularly hazardous on the Island of Hawaii. (For logistical and budgetary reasons, the Island of Hawaii was focused on during the first summer season.)

- ❖ The input and output structures of FLDWAV were examined in preparation for the design of an effective and friendly graphical user interface. In addition, several commercial products had been surveyed that integrated graphical interfaces to both the FLDWAV and HEC models.
- ❖ Field regions were intersected with tax maps, and large landowners, i.e., State of Hawaii, County of Hawaii and Parker Ranch, were contacted for access permission for the fieldwork slated for the third quarter.
- ❖ A meeting was scheduled with PDC operational personnel for April 4 at the PDC facility on Maui. The meeting's purpose was to attempt to tie down product interface requirements at the PDC.

THIRD QUARTER SUMMARY

- ❖ In the third Quarter of this project we remained on schedule for completing a prototype software package by the end of year one.
- ❖ On April 4, Dr. Jene Michaud met with the Pacific Disaster Center (PDC) staff in Maui. Kevin Kodama of the National Weather Service (NWS) also attended the meeting. The main topics of discussion were:
 - (1) Integration of the dam-break-modeling system into the PDC system;
 - (2) Data needs, particularly with regards to topographic data;
 - (3) Proposed procedures for performing dam break analyses and format/content of resulting output;
 - (4) Inundation map from the Waihiawa Dam study;
 - (5) Civil Defense request for flood inundation maps.
- ❖ Conceptual design and analysis of process modules were completed.
- ❖ Several programming methodologies were implemented and examined before arriving at the current method for creating a flood inundation map from the FLDWAV model output.

- ❖ Preliminary design of the user interface was completed. Coding and testing of a preliminary version of the software package was also completed.
- ❖ The field survey was moved from the 3rd quarter to the 4th quarter due to the vast number of landowners that had to be tracked down and contacted for access approval.
- ❖ STI Program Manager, Judy Iokepa, returned from medical leave and resumed management responsibility.

FOURTH QUARTER SUMMARY

- ❖ In the fourth Quarter of this project we remain on schedule for the end of year one.
- ❖ Coding of the prototype software package (M2M—Model to Map) has been completed, and the resulting product demonstrated to the agencies that will use it.
- ❖ A major task during the 4th quarter entailed gaining access to property adjacent to the stream so that fieldwork could be conducted. Considerable effort was expended in obtaining permission from property owners. Responses from property owners were analyzed and responses marked on the tax maps. This assisted the field crew as to which parcels they had access to so that fieldwork could be conducted.
- ❖ Fieldwork, encompassing surveying, measurements, altimeter readings and the like has been completed in the area of the Waimea Reservoirs and immediately downstream. Field crew personnel from the University of Hawaii-Hilo campus were chosen and then hired through a temporary employment agency.
- ❖ August 4, 2000, a meeting was held at the Science and Technology International Honolulu office for the purpose of demonstrating the prototype. In attendance at this meeting were representatives from the National Weather Service, the Division of Land and Natural Resources and the Pacific Disaster Center.

- ❖ A sensitivity analysis was conducted in order to guide future efforts. The analysis is complete and a report is incorporated herein.
- ❖ A user's manual and code documentation are complete. Beta testing of the software was initiated based upon this user's manual.
- ❖ The collection of field data for the Oahu and Kauai projects has been initiated. Island maps, depicting an overview of the entire island, have been ordered and received for Oahu and Kauai. Areas surrounding the potential future study sites were examined on the overview maps, and smaller maps ordered. The Kauai maps were ordered and received. The Oahu maps have been analyzed and compared with maps on-line through the Internet.

Work Accomplished in the 4th Quarter of Year One

FIELD SURVEYS

Gaining access to the field area

Obtaining information for the collection of the property owner data was more involved and complicated than originally anticipated. The collection of the data necessary to run the prototype was initiated in the spring of 2000. The steps followed are outlined below:

- 1) A visit to the tax mapping office is conducted to determine the overall site of the location of the dam and reservoirs and the properties running adjacent to the reservoirs and downstream of the reservoirs.
- 2) Tax maps are obtained in order to identify individual lots.
- 3) Armed with this information, a visit is made to the Real Property Assessment Office. With the tax maps, one can determine the lots adjacent to the stream. This information is then fed into the computer at the tax office, and property owner names and addresses are obtained.
- 4) Letters are forwarded to the owners with consent forms to access the property. A self-addressed, stamped reply envelope is included with the letter for ease in replying.
- 5) Should no reply be received by the deadline date indicated on the consent forms, phone calls are made to those owners whose phone numbers are listed in the phone book.
- 6) Based on the granting of access to the property from the property owners and information received from the property owners, a determination is then made as to where the actual study is to be conducted and where the field team is to go.

Analysis of property owner replies

By way of a brief review, in April 2000, the search for property owners downstream from the Waikoloa Reservoirs #1 and #2 was initiated. This was done with the intention of placing a field team in the study area by early June 2000.

Topographic maps of the subject area were obtained, insuring that UTM coordinates were present on the maps. After determining from a topographical map the direction that the water would flow from the dams, the initial search for property owners, whose land we would need to access, was conducted at the Hilo Public Library.

Tax Maps depicting the stream area and properties adjacent to the stream area were obtained. Thereafter, by searching in the TMK listing book (available in the reference section) we were able to determine the owners of the property and the mailing addresses. Although on its face this seemed like an effective procedure, some of the material was discovered to be out-of-date.

Although the majority of the information was correct, the incorrect information caused a delay in reaching key property owners. An additional problem arose when parcels that were difficult to discern on the public library system smaller (ledger sized) maps, were missed during the initial search.

A subsequent meeting with Dr. Michaud and Dr. James Anderson determined additional lands to be covered in the study. Permission from private residents to allow the field team to conduct the study needed to be obtained. We utilized the Real Property Office and the Planning Office to determine property to be accessed, up to date property owners, and current addresses. This proved to be much more effective and much quicker, as the tax maps maintained at the Real Property Office were larger, easier to read, and the property owners' current mailing information was just a computer terminal away.

The larger landowners, i.e., Parker Ranch, County of Hawaii and State of Hawaii, were contacted via telephone in April to determine their receptiveness in allowing our field crew on their land to perform the study. Initial contact for Parker Ranch was made with

Robby Hind who assured us that there would be no problem with our field team going on Parker Ranch land. The County of Hawaii referred us to the Dept. of Water, and again, no problems were encountered.

The State of Hawaii requested that we go through a hearing process whereby we were to bring in letters of approval from all adjoining property owners to determine whether or not we would be allowed on their land. Letters of approval were requested and received from Parker Ranch and the County of Hawaii.

We enlisted the assistance of Sterling Young of the State DLNR to enable us to gain access for all land held by the State of Hawaii. Mr. Young issued a letter to the DLNR offices of the islands of Hawaii, Oahu, Kauai and Maui requesting their full cooperation for the study. This also proved to be most effective.

A total of 101 parcels were identified to complete the study. They can be broken down as being owned by the following:

- State of Hawaii (13 lots)
- County of Hawaii (one lot)
- Parker Ranch (24 lots)
- Private Homeowners (27 lots)
- Commercial Enterprises (includes trusts, businesses, etc.) (36 lots)

Responses were received from a total of 83 lot owners. Property owners that did not reply could be broken down into two categories: Trusts (Commercial) and Private Homeowners. Trusts or Commercial Enterprises that did not reply totaled 11, while private individuals totaled seven.

Several of the letters addressed to property owners were returned as being undeliverable as addressed. Attempts were made to find new and/or better addresses for these owners, but these attempts were unsuccessful. For owners that did not respond, we attempted to reach them via telephone, however, not all of the owners were listed in the phone book. For those that were listed, phone contact was made, and we were able to obtain signed consent forms from the majority of them or to determine

what was required to obtain a signed consent form. It should be noted that several approval letters were received well after the study had been conducted (some as late as two months after the field work's completion).

Approximately one week prior to placing the field team in the field, a final attempt was made to contact those property owners that had not replied. A representative went to the lot, knocked on the door, and asked what could be done to facilitate the consent being signed. We were able to obtain signed consents on the spot from some of the owners, and were directed to the proper individuals for authorization on others. For those homeowners that were not home, we taped a letter to their door. We received signed consents from several property owners that had the letters taped to their doors.

Of the lot owners that did reply, these can be broken into three categories: Affirmative, Negotiations not resolved or Negative (Refusal).

- A total of 51 approvals were received. The State granted 13 approvals and the County granted 1 approval. Commercial enterprises' approvals totaled 23 and private homeowner approval totaled 14. Some of the commercial enterprises required hold harmless agreement(s) and/or insurance certificates. This delayed the access issue, but most was met in a timely fashion.
- We had entered into negotiations with several commercial enterprises (7) and one private landowner, however, the project had been completed before negotiations were completed.
- A total of 25 refusals were made. The bulk of the refusals came from Parker Ranch, with (24) refusals of access to property. The other refusal was from a private individual.

When written authorization was received, the individuals were placed on a "call list." These individuals were called approximately one week prior to fieldwork commencing to verify that the field team could indeed work on the property, and to advise of a target date for when the team would be on the property. Most homeowners requested an additional 24-hour notice, and to the extent that this was possible, this was done.

For the next property owner search, new methods were employed in light of the properties not being on island. For Kauai, an initial search was made at the Kapa'a Public Library for property owners. Unfortunately, the material contained at the Library was severely out-of-date as the most current maps that could be obtained and reviewed still reflected 'Territory of Hawaii.' This search was further complicated by the TMK reference available at the library. The key available was a reverse filing system. If you have the owner's name, you could determine the property they owned. This was not a feasible way of conducting a study. Nonetheless, the initial parcel sections were determined.

A second search was conducted on July 31 at the Real Property and Planning Offices. At that time, tax maps for the Waita Dam, and all properties running downstream, was determined.

The search for the Oahu properties was tackled differently. The initial Zone Map was ordered from the Hilo Public Library. This breaks down the island into a series of zones from which Zone Master Maps are ordered. From the Zone Master Maps, the Section Maps are determined. Lot maps can be obtained from the Planning Office in Honolulu. There are approximately 2000 Section/Lot maps within the County of Honolulu, and these maps are available on a customized CD Rom. Once it has been determined definitively which Zone/Section/Lot Maps are needed, the list will be provided to the County of Honolulu for ordering. The list of property owners can be obtained from the Internet.

Collecting Data

James L. Anderson, Ph.D. of the University of Hawaii—Hilo campus, was subcontracted to conduct fieldwork. Methodology employed for the surveying of the areas included GPS (Trimble), altimeter readings and physically measuring the areas with a taped measuring device. Because GPS readout information was not always available due to the heavy tree canopy, barometric leveling was employed through the use of altimeters. See Appendix A. for additional details.

SENSITIVITY ANALYSIS OF THE DATA

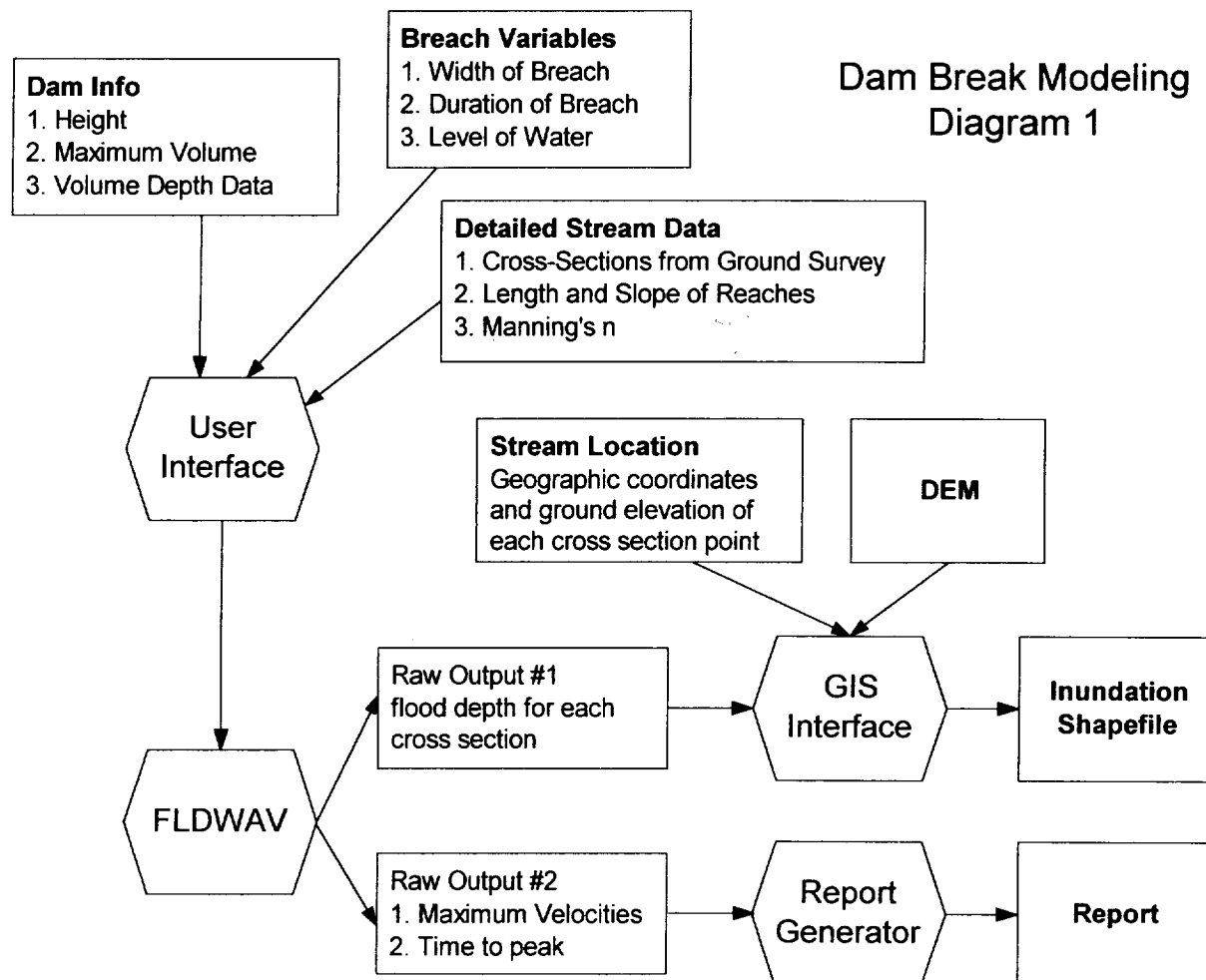
Data sensitivity analysis was initiated based on the data gathered in the field. The complete analysis of the initial data set is incorporated herein as Appendix B.

COMPLETION AND DEMONSTRATION OF THE M2M PROTOTYPE

This year, the technical portion of the project focused on the core product, the creation and automation of flood inundation maps. The application has been named M2M for **Model to Map**. A complete discussion of the software and our approach is included in the User's Manual and incorporated as Appendix C.

Components

The M2M software package has several components (see diagram 1):



The user works within the context of an M2M “Workspace” which is an ArcView “View” document with a customized menu and tool bar. The Workspace functionality includes all of the original View functionality, and provides the additional capabilities of:

- Convenient interfaces to the FLDWAV, FLDGRF, and FLDINP models;
- Tools for mapping survey points onto flood paths, providing the survey point eastings and northings, and distance along the stream from the dam;
- Tools to aid in preliminary assessment by extracting survey point elevation and streambed cross-sectional data from a Digital Elevation Model (DEM);
- Functionality to facilitate the importing, cropping, and filling of DEMs;
- Production of an Inundation Map, using the FLDWAV “Profile of Crests and Times” output, in conjunction with the underlying DEM and vector representation of the flood path;
- Classification of the flood waters into varying depth and color intervals for easy visual assessment of flood criticality; and
- Capability to export the extracted FLDWAV output to an Excel spreadsheet or other report format.

Requirements

The software required in running M2M includes:

- ArcView 3.2 with Spatial Analyst;
- NWS Software FLDWAV, FLDGRF and FldInp; and
- Microsoft Excel Spreadsheet.

The data required to run M2M includes:

- 10 meter Digital Elevation Model (DEM);
- Paper and electronic (TIF) standard topographic maps;
- Information about the dam (type, maximum volume, etc.); and
- Information downstream of the dam (flow path, channel shape, roughness; etc.).

Concerns about the software include the FLDWAV model being numerically unstable and FldInp being available only in its Beta release and requiring further modification.

Methodology

Several methodologies were implemented and examined before arriving at the current and final method. All methods begin with an ArcView theme of point shapes depicting the FLDWAV model output of water depth at various points along the river following the dam break. The water depths at these points were used to interpolate a water depth for each pixel comprising the river shape.

Our final method is based on a preliminary methodology developed by the NWS known as the “onion skin” approach. This method, and our further development of the approach for this application, is discussed in detail in the User’s Manual (Appendix C).

Demonstration

A meeting was held on Friday, August 4, 2000 at 10:00 a.m. in the STI Conference Room of the Honolulu office in Grosvenor Center. The purpose of the meeting was to demonstrate the prototype of the M2M Software, as well as to discuss the methodology employed in gathering data. The presentation encompassed:

- Overview of the project;
- Software Development;
- Application to the Waikoloa Reservoir Site;
- Fieldwork conducted; and
- Deliverables and Schedule.

Judy Iokepa presented the Overview of the Project, Fieldwork, and Deliverables and Schedule and Dr. Michaud made the presentation of the Software Development and its application to the Waikoloa Reservoir Site. At the end of the presentation, Dr. Michaud and Jillian Marohnic demonstrated the software. In attendance were the following:

Mike Jones from STI-Honolulu (mikej@sti-hawaii.com)

Ron Seiple from STI-Honolulu (seiple@sti-hawaii.com)

Carol Tyau from DLNR (c_tyau@yahoo.com)

Edwin Matsuda from DLNR (ed_matsuda@yahoo.com)

Sterling Young from DLNR (dowaldpm@pixi.com)

Kevin Kodama from NWS (kevin_kodama@noaa.gov)

Stan Goosby from PDC (sgoosby@pdc.org)

Jillian Marohnic from STI-Hilo (jillian@sti-hawaii.com)

Jené Michaud from U.H. Hilo (jene@hawaii.edu)

Judy Iokepa from STI-Hilo (judy@sti-hawaii.com)

Jill Dahlman from STI-Hilo (jdahlman@sti-hawaii.com)

User's Manual

A Beta Release User's Manual has been completed. The user's manual is incorporated herein as Appendix C. Beta testing of the software was initiated based upon this user's manual.

Work to be Completed in Year Two

FIELD SURVEYS

Preliminary model runs

Preliminary inundation maps for year two surveys for the other high hazard dams will be run to determine the geographic extent of the possible inundation areas. This will be accomplished using the M2M prototype and Simple Dambreak. These maps will better allow us to identify the extent of public involvement in gaining access to the stream channels.

Initiation of location of property and property owners on Oahu and Kauai

The initial Oahu tax maps have been examined, and select maps have been ordered. Once detailed maps are received, it will be necessary to determine property owners. Letters will also need to be sent to these property owners, obtaining permission to access the land, as was accomplished in the Waimea project.

The enhanced, detailed tax maps surrounding the Waita Dam on Kauai and following the local stream to its flow to the ocean have been ordered and received. The next step will be to determine property owners. Letters will also need to be sent to these property owners, obtaining permission to access the land, as was accomplished in the Waimea project. This should be undertaken within the next two quarters.

FINALIZATION OF SOFTWARE AND USER'S MANUAL

Incorporation of user's feedback

Once the prototype is installed at the Pacific Disaster Center, a list the user compiles with changes and fixes, will be implemented within the software and the users manual. Feedback will be gathered throughout the first quarter of year two.

Before the integration can be accomplished, it will be necessary for the PDC to provide us with their integration requirements. This has not yet been developed by the PDC and we are awaiting their instruction.

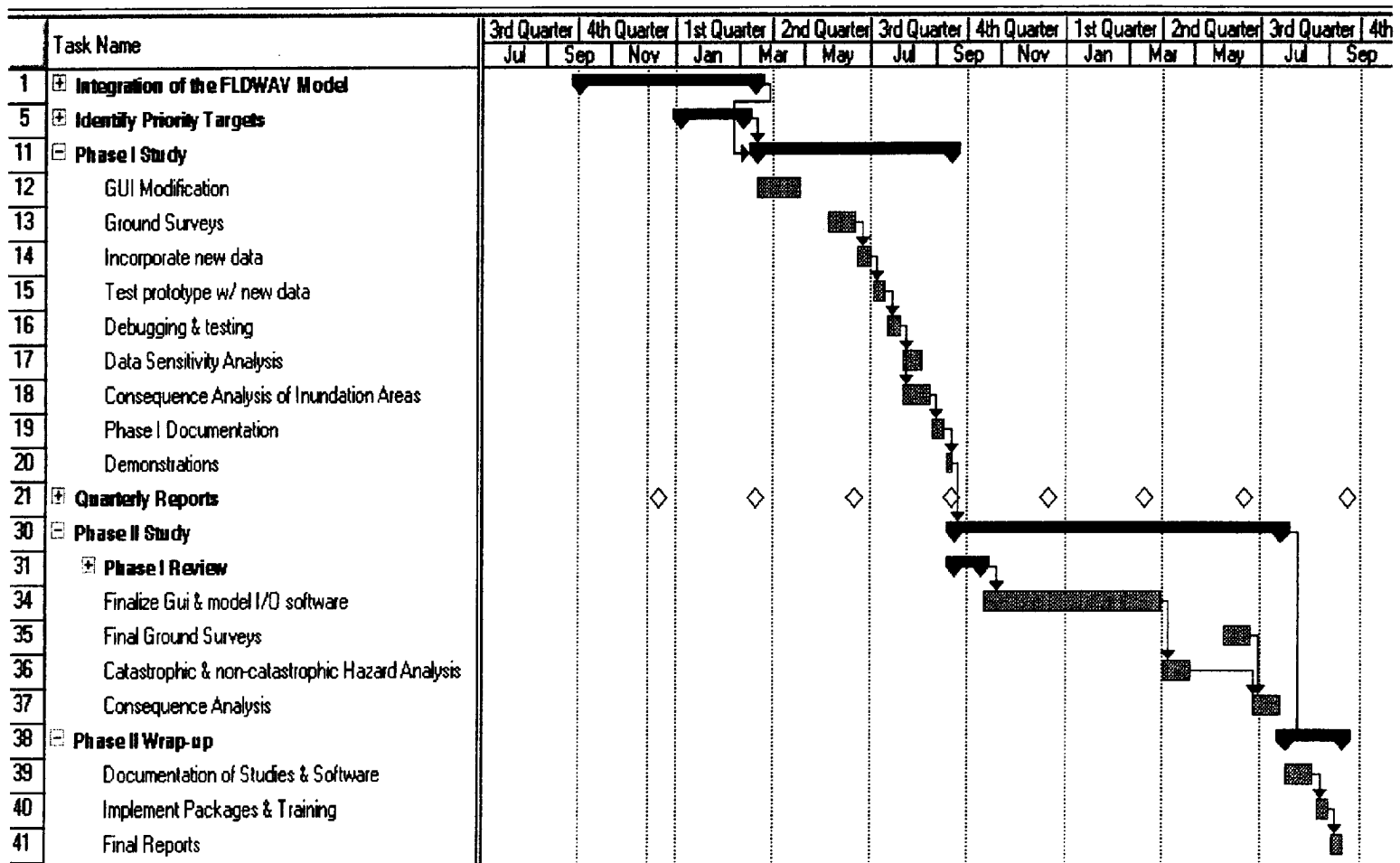
Implementation of finalized software

The finalized software will be installed for system compatibility and incorporation into the Pacific Disaster Center's Software Schema in the fourth quarter of year two. Training will follow as convenient for the staff at the Pacific Disaster Center.

REPORTS

A comprehensive sensitivity analysis will be conducted once data has been collected at additional test sites. Additionally, a consequence analysis of surveyed inundation areas will be compiled as well as the quarterly reports and final report as required by the NASA contract.

Project Schedule



Appendix A: Field Survey Report

Submitted by James Anderson, Ph.D.

PURPOSE

The objective of the surveying of the stream channels is to provide ground truth for the computer model that is currently using a Digital Elevation Map (DEM). This involves collecting elevation control point data as well as documenting the details of the stream channel morphology.

METHODS USED

Many standard surveying methods depend upon line-of-sight in order to obtain useful information. This method could not be used effectively in the project area. Had this type of surveying method been chosen, employment of such methods would have required physically clearing all vegetation from the light path. As this was not either economically or logistically possible, methods were employed that were portable, independent of line-of-sight, or that required only short-range visibility.

Barometric leveling.

This method ideally employs two identical calibrated precision surveyor's altimeters. In the initial stages of this project, we decided to use one of these instruments in conjunction with a precise digital altimeter.

Non-identical altimeters are not desirable where topography is steep because of the need for systematic temperature corrections. In most of the Waimea area, however, elevation changes are small from station to station so that temperature corrections were unnecessary.

Altimeters are actually barometers that are graduated to read out in elevation units. A change in the observed elevation on an altimeter can be caused by either:

- 1) Change in actual physical elevation or

- 2) In situ change in the ambient atmospheric pressure due to fluctuations within the air column.

The latter is mainly the result of the temperature and humidity variation with temperature being the more significant of the two. An uncorrected reading can thus be in error by many tens of feet over a short time interval. Provisions are made to compensate for this situation by establishing a fixed base station.

The purpose of the fixed base station is to collect data that can be used to construct a drift curve during the period of the survey. Field readings can be corrected. Noting the time of the observation and comparing the information to the drift curve enables corrections to be made immediately. In the Waimea project, we elected to maintain radio contact with the base station in order to correct our readings at each field station. A written record was kept at the base station for later review.

The elevation of the base station was measured via repeated readings taken on a known elevation point along Highway 19 (219060E 2216590N; 2567 feet elevation), and using the double altimeter approach described above.

The surveyor's altimeter used is calibrated to 50 degrees Fahrenheit. For field temperatures above this, the correction is minus when the field reading is lower than the base station and positive when it is above the base station. The correction is applied as a percentage of the elevation difference between the base and the field station. Temperature corrections were applied to the steep terrain in the vicinity of the Waimea reservoirs.

Measurements using surveyor's altimeters were reproducible to plus or minus 2 feet.

Global Positioning Systems (GPS) survey.

Wherever possible, GPS positions were obtained along the line being surveyed. All measurements were made using a Trimble Navigation GPS XR-Pro backpack portable receiver. Results were printed out via a computer interface in Universal Transmercator System (UTM) coordinates and the North American Datum (NAD83 datum). Elevations were given in feet.

Almanac Position Dilution of Precision (PDOP) data was reviewed on an ongoing basis to plan campaigns during periods of optimum satellite orientation and availability. Occupations were typically short, but long enough to ensure beacon reception and acceptable PDOP.

Repeated readings on the same point typically yielded sub-meter accuracy in the horizontal and approximately 2-meter accuracy in the vertical.

Hand Leveling.

This method employs a procedure similar to that of precise level surveys wherein two rods are held at the end points of an interval and an optical telescopic hand level is used to site to each rod. The height difference between the two rods is then determined, typically to an accuracy of one tenth of a foot (1/10'). This method was useful in steep terrain and in determining the details of inner channel morphology.

Taped distances.

All slope distances were taped using a 300-foot surveying tape mounted on a spool. The accuracy of this method is approximately plus or minus one foot. Distances can also be obtained from Global Positioning System (GPS) data with accuracies of 1.5 to 3 feet.

ANALYSIS OF METHODS AND RECOMMENDATIONS:

Barometric Leveling.

The calibration factor for the digital altimeter was not known. It would be desirable to obtain a second surveyor's altimeter with the same calibration factor.

Human error may be a factor because the surveyor's altimeters are manually set for each reading. I recommend that this be evaluated by having a large number of repeat readings taken on the same mark by the same person. This will have the additional benefit of increasing the reader's proficiency in setting and reading the instrument. A base instrument will need to be monitored nearby to determine drift, if any during this experiment.

My impression is that we could get better accuracy by keeping the base station as near to the field area as possible. This may require frequent moves, but the added precision would be well worth the time and effort.

In Waimea, for example, fairly strong trade winds blow across the area during the day causing rapid temperature and humidity fluctuation at the base station. Field readings taken downwind from the base station would be expected to have a delayed response to factors causing drift at the base station. Similarly, field readings taken upwind would have responded earlier to conditions causing drift at the base station. High wind conditions in general are detrimental to barometric surveys. Keeping the altimeters in as close a proximity to each other as possible can mitigate this factor.

GPS surveys.

Occupation time may be a factor in the precision of these readings. I recommend conducting some experiments to evaluate this via repeated occupation of known sites.

PDOP is certainly a factor. This could be evaluated concurrently with the occupation time experiment.

Tree canopy and large buildings were a negative factor during the field surveys. Often readings could not be obtained, particularly in the critical channel axis areas. Some of this problem can be mitigated with an extended antenna shaft, used to raise the antenna above surrounding foliage. Elevations can be easily corrected by subtracting off the additional known height above the ground. Also, trees and other obstructions limit the number of satellites that can be used for fixes and thus degrade the reading. In some cases, a long occupation of a position would have been impossible because a lock could only be obtained for a few seconds.

Elevations are typically not as precise as horizontal positions with GPS because of the way that the satellite signals intersect in three dimensions. The results of our field surveys suggest that there is a systematic positive error with the GPS determined elevations.

An interesting result, however, is that the elevation differences between points are similar in magnitude to those obtained with barometric leveling. This raises the possibility of adjusting the GPS results to absolute elevation by finding the elevation difference at one or more known elevation control points. I recommend testing this idea by comparing both altimeter and GPS readings along a profile controlled by precise level surveying (e.g. accurate to 1mm).

Hand leveling and taping of distances.

I would like to use this method more extensively. It is easily taught to the field party, is portable in rough terrain, and produces excellent precision, particularly in the channel areas. Similarly, taping is easily taught and applied. The main limitation to taping is in keeping the tape taut in rough terrain. Slope distances also need to be converted to map distances.

Summary of Fieldwork

The following is a summary of the fieldwork conducted on July 10, 11, 12, 13, 14 and 28:

Members of the field team that began working in Kamuela (Waimea) the week of July 10-July 14 included Field Team Manager, Dr. Anderson, STI Project Coordinator, Jill Dahlman, and Field Assistants, Alan Burt and Kirsten Werner.

Tuesday, July 11, marked the first day in the field. The base station was set up at Waimea Park, Lindsey Road, Kamuela (Waimea). Kirsten worked at the base station, while Jill and Alan worked in the field with Dr. Anderson. Elevations were established at the base camp and at the altitude marker (benchmark) noted on the topographic map. These elevation marks were not given a Station Number.

The area covered on this day was owned by the State of Hawaii and leased to the University of Hawaii in the area known as TMK 6-6-3. The channel of Waikoloa Stream was mapped (specifically lots 6 and a portion of 7), and given the designation 1 AX (#) at each point. Bearings were taken and distances were taped. Thirteen (13) points

were taken that day, and approximately 1/2 of the stream channel was mapped. The stream channel was choked with vegetation and debris.

On Wednesday, July 12, the base station was again established at Waimea Park. Alan worked at the base station, while Jill and Kirsten worked in the field with Dr. Anderson. Elevations were calibrated and the mapping of the channel continued at the final point from the previous day.

The first point of the day was designated as 1AX13a. Mapping of TMK 6-6-3 (specifically lot 7) continued until the edge of the boundary of Lot 7 with TMK 6-5-3-4. This was Parker Ranch land. (Parker Ranch had originally given permission for the field team to take measurements on the land, but subsequently rescinded that approval for unspecified reasons.)

The final notation for the mapping of the Waikoloa stream channel was designated as 1AX20. At or near point 1AX16 a dam was noted. The dam appears to be of cement and metal pole construction. It had been broken in this area, and the location had numerous branches, logs, lumber and debris piled in a heap. Again, the entirety of the stream channel had vegetation and debris, with some areas being clearer than others.

Having completed the mapping of the stream channel, the mapping of the transverse sections of Waikoloa Stream was initiated. The methodology employed included plotting of GPS points, taking altitude readings at the base of the Waikoloa Stream channel and at the edge of the stream channel (as well as any outlying points that were significant), and taking taped measurements of the area to the stream channel base. The initial transverse bisected TMK 6-6-3-6 at or near its junction with TMK 6-5-3-38. Three northerly points were taken (1TR1N-1TR3N), and two southerly points were taken (1TR1S-1TR2S).

A second transverse section was taken at TMK 6-6-3-6 at or near its junction with Opelo Road. Two northerly points were taken, and two southerly points were taken (2TR1N-2TR2N and 2TR1S-2TR2S, respectively).

On Thursday, July 13, the base station was again established at Waimea Park. Kirsten worked at the base station, while Jill and Alan worked in the field with Dr. Anderson. Elevations were calibrated and the transverse mapping of the Waikoloa Stream channel continued, employing the same methodology noted above.

Points designated 3TR were located along TMK 6-5-3-44, 6-6-3-7, and 6-5-3-8, at one point bisecting the point designated 1AX19. This area was thickly vegetated, necessitating the sawing of many branches, tall grasses, etc. to traverse. Three southerly points were plotted, and five northerly points were plotted.

Two additional points (one northerly, one southerly) were plotted to add to the data collected for 2TR. Readings of altitude and GPS notations were obtained at these two points.

A fourth transverse section was made at or near TMK 6-5-4, bisecting lots 15, 10 and 12. Care was made to insure no trespass on to Parker Ranch land. This traverse was by far the easiest of the day, especially when aided by local residents who pointed out a trail commonly used.

A conversation with the residents noted that the trail we utilized originally went to the area surrounding the reservoirs, but that the water company had sawed down branches and left much debris in the stream channel and along the trail. The residents were concerned about a fire hazard and about the impediment to the flow of the stream.

Points were plotted at the center of the Waikoloa Stream bed channel and noted 2AX#. Two northerly points (designated 4TR#N) and three southerly points (designated 4TR#S) were noted.

On Friday, July 14, the base station was again established at Waimea Park. Alan worked at the base station, while Jill and Kirsten worked in the field with Dr. Anderson. Elevations were calibrated and the transverse mapping of the Waikoloa Stream channel continued employing the same methodology noted above.

The first section noted encompassed the area TMK 6-5-5-20 and 6-5-5-1. Care was taken to not work beyond the center of the Waikoloa Stream bed channel so that trespassing on to Parker Ranch land was not an issue. Accordingly, only 2 southerly points were taken designated 5TR#S.

The second section noted encompassed the area TMK 6-5-6-5 and 6-5-6-12 that included the area of the Waiaua Stream. Base camp was relocated to a private road adjacent to TMK 6-5-6-5. Two northerly points were taken (6TR#N) and two southerly points were taken (6TR#S), together with one stream channel center point.

The final section mapped encompassed the area TMK 6-5-3-29 and 6-5-3-1. This area was of a portion of Waikoloa Stream. Two northerly points and two southerly points were taken and designated as 7TR#N and 7TR#S, respectively.

On July 28, the field team set out to clarify points previously taken and to take new transverse sections of the gulch area immediately downstream from the dams. In the field were Dr. Anderson, Dr. Michaud (Project Co-Investigator), Jill Dahlman from STI and Alan Burt. Kirsten Werner sat at base station with the altimeter.

The work in the field began at approximately 9:30 a.m. and ended at approximately 4:30 p.m.

The initial clarification point was at the bridge on Opelo Road. New altimeter readings were taken for the purpose of comparing with old data. Dr. Michaud and Jill went into the streambed to draw a cross section of the area immediately upstream from the bridge.

Alan and Dr. Anderson re-took the altimeter readings and measurements from the stream channel to the next rise in slope. The stream had ~2' of water in it on this day. It should be noted that the previous visits to the site revealed a dry streambed.

The next site visited was approximately .2 miles from the gate to the dams at the end of Spencer Road. This site was steep and the stream channel was accessed by way of a pig trail utilizing the "sliding down" method (a/k/a "cascading"). This area was noted to have a slot canyon. Measurements were taken of a representative section and the

group proceeded to exit the area utilizing rock climbing techniques. The stream channel had little to no water in it, except at the base of the slot canyon, where a stagnant pool had formed.

The next site was near the top of the hill, and close to the reservoirs. Measurements were taken of the stream channel (which is small) and leveling rods were used to complete the measurements. The base station was moved to this location for clearer communication purposes (range for communicators). No water was located in the stream channel.

The final site accessed was down into the gulch, which was extremely steep. Again, the site was accessed by way of pig trail. The area was searched for a representative section and measurements were then taken at two different points along the stream channel. Very little water was located in the stream channel. The team exited the area using rock climbing techniques and utilizing trees for handholds.

RECOMMENDATIONS.

For the next field study, the following recommendations are made:

1. A day of scouting the area for ease of access and characteristics of the terrain may prove beneficial. For areas requiring clearing prior to access, this day could be utilized for that purpose.
2. The current configuration of one person at a base station and the field manager and two field assistants in the area of study should be maintained. This was highly efficient and led to ease of data collection.
3. An additional set of radios should be purchased for the team in the field. This would enable all members of the team to be in constant contact without visual aid.
4. A printout of the GPS satellite availability as well as a TMK review (for access purposes) would be helpful. The need for additional

maps and/or access should be established at this time. This should take place prior to going into the field.

5. Maintaining an individual in the field who has complete knowledge of what property owners had permitted access to which lots was considered essential by the Field Team Manager, Dr. Anderson.

INFORMATION OBTAINED

The raw data obtained by the field crew follows:

Code Description

Waimea Base Station Info

#AX# A point with this given designation indicates the position within the stream channel. Generally, new designations were made at areas within the channel that had a noticeable bend. Distances were taped, beginning at the bridge and continuing through the center of the stream channel. Where there is a skip in the UTM coordinate indicates a poor beacon reception and a location that could not be plotted.

1AX was the area between the bridge and the edge of the State of Hawaii land in TMK 6-6-3. 2AX and 3AX were midpoints of the stream channel within a TR (cross section) of the stream.

#TR# A point with this given designation indicates that the point marked is a measurement of a cross section of the stream, followed by a bearing (north/south). The number indicates the location. The #1 would be the location from the center of the stream channel to the edge of the stream channel. The #2 would be the location from the edge of the channel to the first noticeable rise in terrain. The numbering system continues until such time as the flood plain ends. There are 7 such indications from the first week out in the field.

POINT	UTM N	UTM E	LAT (N)	LONG (W)	ELEV (FT)	ELEV (M)
1AX1	2215862.548	219935.67	20-01-09.63065	155-40-36.91811	2619.632	798.464
1AX2	2215877.284	219969.407	20-01-10.12703	155-40-35.76629	2613.973	796.739
1AX4	2215901.365	220035.231	20-01-10.94383	155-40-33.51642	2626.875	800.672
1AX5			20-01-11.30229	155-40-33.26631		800.743
1AX5A	2215912.208	220042.925	20-01-11.30018	155-40-33.25786	2626.739	800.63
1AX6	2215888.003	220087.655	20-01-10.53687	155-40-31.70666	2623.182	799.546
1AX13	2215959.748	220324.198	20-01-12.99123	155-40-23.61334	2641.532	805.139
1AX13A	2215935.174	220320.376	20-01-12.84062	155-40-23.74223	2631.84	802.185
1AX14	2215991.92	220292.809	20-01-14.02040	155-40-24.71022	2633.041	802.551
1AX17	2215991.716	220292.638	20-01-14.01367	155-40-24.71598	2629.161	801.368
2AX1	2216573.506	221123.024	20-01-33.350605	155-39-56.48396	2705.024	824.491
2AX2	2216350.82	221024.895	20-01-26.06327	155-39-59.73639	2682.553	817.642
3AX1	2216676.169	218553.734	20-01-35.34944	155-41-24.88101	2510.543	765.213
1TR1S	2215814.941	219927.164	20-01-08.07916	155-40-37.18436	2626.331	800.506
1TR2S	2215762.228	219921.119	20-01-06.36304	155-40-37.36321	2626.069	800.426
1TR1N	2215893.062	219938.891	20-01-10.62389	155-40-36.82418	2622.405	799.309
1TR2N	2215967.226	219949.638	20-01-13.03954	155-40-36.49550	2632.017	802.239
1TR3N	2216004.537	219955.806	20-01-14.25524	155-40-36.30397	2641.903	805.252
2TR1N	2215883.354	220143.861	20-01-10.41499	155-40-29.77165	2636.352	803.56
2TR2N	2215906.024	220147.905	20-01-11.15380	155-40-29.64505	2643.292	805.675
2TR3N	2216028.629	220167.918	20-01-15.14840	155-40-29.02438	2650.584	807.898
2TR1S	2215848.434	220147.588	20-01-09.28218	155-40-29.62431	2646.776	806.737
2TR2S	2215790.713	220145.156	20-01-07.40518	155-40-29.67617	2644.17	805.943
2TR3S	2215748.236	220169.396	20-01-06.03743	155-40-28.81941	2652.667	808.533
3TR2N	2216081.283	220296.255	20-01-16.92618	155-40-24.64087	2648.791	807.351
3TR3N	2216163.242	220296.453	20-01-19.58963	155-40-24.67910	2650.778	807.957

3TR1.5S	2216007.518	220382.638	20-01-14.57393	155-40-21.63030	2655.526	809.404
3TR4S	2215725.139	220648.243	20-01-05.53548	155-40-12.34327	2663.073	811.705
3TR5S	2215671.41	220699.704	20-01-03.81619	155-40-10.54445	2681.472	817.813
4TR2N	2216597.998	221089.238	20-01-34.12903	155-39-57.65960	2711.339	826.416
4TR1N	2216578.474	221111.348	20-01-33.50606	155-39-56.88698	2710.028	826.016
4TR1S	2216567.077	221136.799	20-01-33.14885	155-39-56.00736	2712.549	826.785
4TR2S	2216540.269	221177.57	20-01-32.29881	155-39-54.59082	2711.002	826.314
4TR3S	2216527.207	221211.342	20-01-31.89185	155-39-53.42248	2719.233	828.822
5TR1S	2216344.423	221025.369	20-01-25.85562	155-39-59.71660	2696.66	821.942
5TR2S	2216315.729	221041.689	20-01-24.93162	155-39-59.13973	2690.535	820.075
6TR2N	2216839.069	218567.266	20-01-40.65012	155-41-24.50585	2539.653	774.086
6TR1N	2216681.852	218546.618	20-01-35.53040	155-41-25.12882	2519.007	767.793
6TR1S	2216661.784	218550.183	20-01-34.88014	155-41-24.99512	2521.397	768.522
6TR2S	2216615.134	218546.298	20-01-33.36218	155-41-25.10289	2523.217	769.077
6TR1AN	2216682.546	218556.898	20-01-35.55835	155-41-24.77574	2519.535	767.954
7TR2N	2216113.679	220618.962	20-01-18.14649	155-40-13.56329	2674.193	815.094
7TR1S	2216012.593	220673.499	20-01-14.88984	155-40-11.63270	2669.891	813.783
7TR2S	2215909.103	220693.067	20-01-11.53694	155-40-10.90310	2669.571	813.685

Appendix B: Data Sensitivity Analysis

INTRODUCTION

In order to make flood maps using *FLDWAV* and *M2M* one must acquire certain types of data and make a series of assumptions about the dam breach and the channel/floodplain characteristics downstream of the dam. The accuracy of the resulting flood map will, of course, be influenced by the validity of the assumptions and the accuracy of the data used. The purpose of the sensitivity analysis is to determine—for the Waikalua test case—to what extent the final flood map is influenced by certain key assumptions and data choices.

The dam break simulations presented herein are for the Waikalua #1 Reservoir, which is located about one mile above the town of Waimea on the island of Hawaii. Should the earthen dam fail, the resulting flood will first pour into a deeply incised and rather steep gulch. After flowing for about half a mile, the flood will leave the gulch, which ends when the stream reaches the relatively flat ground on which the town of Waimea is built. (This relatively flat area will hereinafter be called the “Waimea floodplain.”) Within the town itself the stream channel is not very large and the flood will overflow its banks. The question is exactly how far the flood will spread out and exactly how deep the water will be.

SIMPLE DAMBREAK VERSUS FLDWAV

Comparison of Model Features

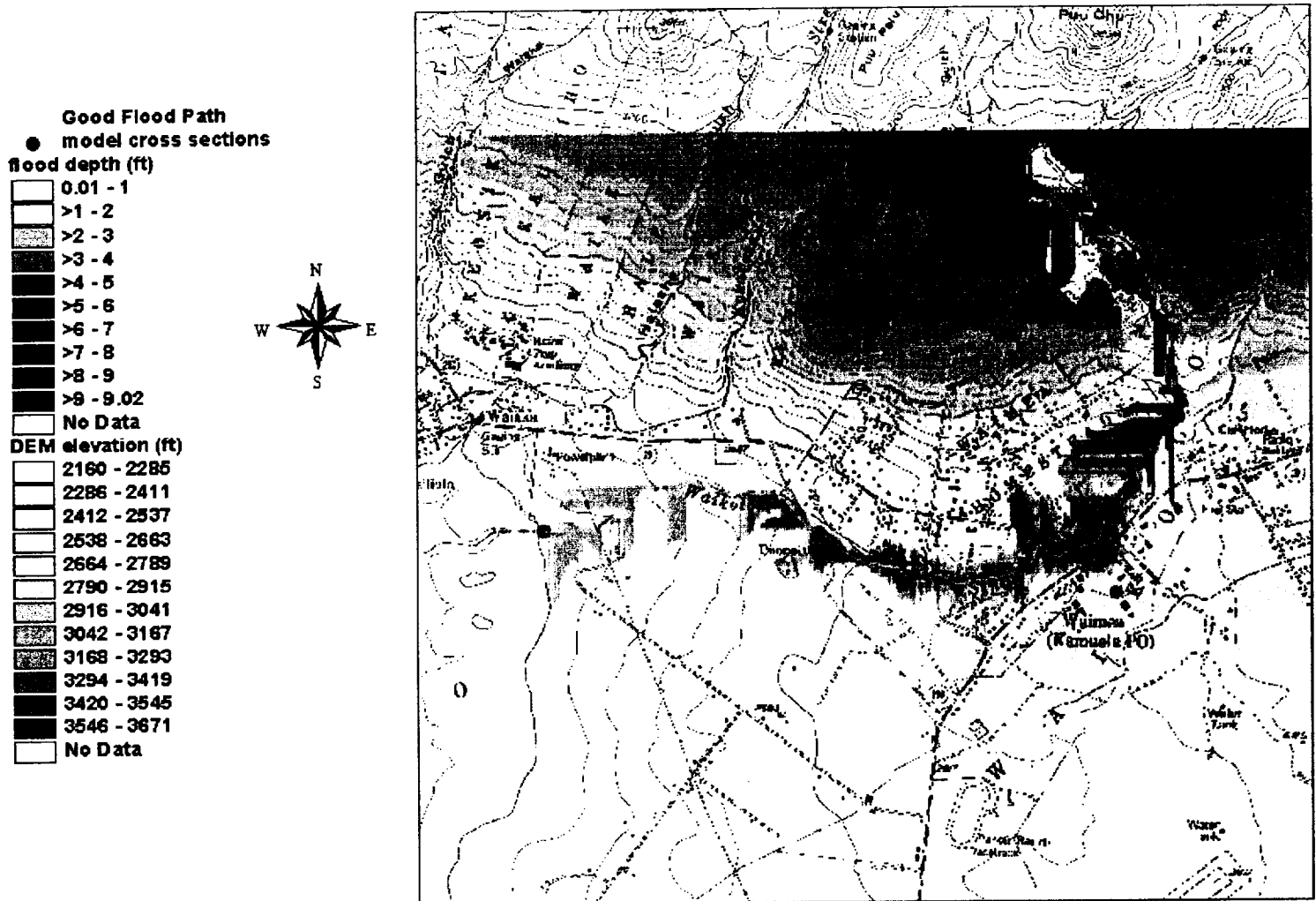
FLDWAV represents the state-of-the-art in modeling dam break floods, but many users find it difficult to use. The NWS therefore wrote the *Simple Dambreak* model for situations when rapid results are required. *Simple Dambreak* makes a series of simplifying assumptions, and its solutions are not as accurate as *FLDWAV*'s solutions. Some of the original reasons for preferring *Simple* are now obsolete. For example, *Simple*'s run time is shorter than *FLDWAV*'s, but today's faster computers make this advantage inconsequential. Another difficulty with *FLDWAV* is that constructing input files by hand is difficult and time consuming. In comparison, *Simple*'s input files are

shorter, simpler, and easier to understand. The recent release of *FLDINP* (the program which aids the user in constructing *FLDWAV* input files) partly alleviates the problems associated with *FLDWAV* input files. One further difficulty associated with *FLDWAV* is that it can be subject to numerical instabilities that render the solution suspect or cause the program to crash prematurely. In terms of output, *FLDWAV* provides more information about the simulated flood. (Only *FLDWAV* provides information on flood velocities and the duration of flooding.)

Comparison Simulations for Waikaloa Reservoir

The *FLDWAV* simulation was conducted under the assumption that the dam fails by piping and that the breach takes 15 minutes to develop. (The two possible failure modes are piping and overtopping. It is here assumed that failure by piping during an earthquake is the most likely failure mode.) The breach width (62 ft) and time duration (15 minutes) were estimated as a function of dam height, volume and surface area, using equations found in the *FLDWAV* user guide. The *Simple* model assumes that the dam failure is due to overtopping. The breach width (120 ft) and time duration (15 minutes) were estimated from the dam height using guidelines contained in the *Simple* user guide. Both simulations were conducted using identical channel topography and roughness. The channel topography was extracted from the DEM, and roughness coefficients were estimated based on field observations and recommendations found in Chow (1959). The procedure for producing an inundation map from *FLDWAV* output is essentially the same as that for producing an inundation map from *Simple* output.

The inundation maps from the two simulations are found in Figures 1 and 2. In inspecting these maps one should keep in mind that the exact width of the flooded area is a function of the flood elevation *and* the number of iterations (onion skins) employed in producing the flood map. In each map the number of iterations is sufficient to show which portions of the Waimea floodplain are flooded to a depth of at least one foot. In some of the higher elevation areas, the simulated flood overtops the topographic divide and begins to flow down a new stream channel. In these particular stream channels, the number of onion skin iterations was insufficient to show how far the flood would extend down the new channel.

Figure 1 - Flood from 15 minute Piping Breach

The most important aspect of the inundation maps is the flood depth in inhabited areas. The following table shows the flood depth at three locations in Waimea Town.

	FLDWAV flood depth (ft)	SIMPLE flood depth (ft)
Turnoff to Waikaloa Reservoir (residential neighborhood above Waimea commercial district)	6.2	5.9
Stoplight at highway intersection (Waimea commercial district)	4.3	3.7
Turnoff to Puepelu Reservoir (residential neighborhood below Waimea commercial district)	4.5	4.6

Both models predict similar times between the beginning of the dam failure and the time of maximum flooding. *FLDWAV* predicts that downtown Waimea will be flooded within 19 minutes, compared to a prediction of 23 minutes from the *SIMPLE* model.

Summary and Conclusions

In the Waikaloa test case, the differences between the two simulations are modest (less than 10%). Either simulation tells essentially the same story: a dam breach will cut off the highway within 15-30 minutes, and several neighborhoods plus the commercial district will be flooded. Utilization of the *Simple* model would be justifiable when a highly accurate solution is not required and there is neither time nor expertise for developing *FLDWAV* input files. Another circumstance when the *Simple* model could be preferred is when *FLDWAV* is experiencing numerical instability. It should be noted that there are also “work around” solutions that could be used to deal with *FLDWAV* instability. In cases where a flood inundation map is released to the general public it is preferable to use the more accurate model (*FLDWAV*). *Simple* might be better suited,

however, for doing preliminary simulations to get a better idea of what specialized topographic data is needed.

SOURCE OF TOPOGRAPHIC DATA

Possible Sources of Topographic Data

Possible sources of topographic data for Hawaii include: 1) standard contour maps on paper (7.5 minute quadrangles published by the USGS, 2) scanned electronic versions of the paper maps, 3) 10-meter Digital Elevation Model (DEM) data, and 4) localized topographic data obtained through field surveys. It should be noted that the DEM has been derived from the 7.5 minute contour maps, so the major difference between them is format, not content.

How the Data is Used

In the current context, topographic data is needed for two main purposes. The first is to parameterize the topography as seen by the *FLDWAV* model. From the viewpoint of the (1-D) model, the channel consists of a series of end-to-end sections. In longitudinal profile, each section is characterized by its upstream/downstream elevation and length (and thus slope). The model also requires the channel cross-sectional shape at the end of each section. The channel cross-sectional shape is established by specifying the channel width at various elevations. Either the 7.5 minute contour maps or the DEM can be used to obtain the topographic information required by *FLDWAV*. The advantage of using the DEM (in conjunction with the electronic copy of the contour map) is that extraction of the topographic data using *M2M* is relatively automated, and easier than trying to get precise elevations from the contour maps.

Experience obtained during the Waikalua Case Study showed that the USGS topographic data (both the 7.5 minute contour maps and the DEM) are satisfactory in terms of describing the longitudinal channel profile. Whether or not the USGS data is satisfactory in terms of describing the channel's cross-sectional shape is open to question. Use of field survey data to quantify the channel's cross-sectional shape is, therefore, the subject explored in the following section.

The second use of the topographic data is for establishing the 2-D flood depths by overlaying the 1-D flood depths from the model onto the 2-D topography. A DEM is the only type of topographic data that can conveniently be used for this purpose.

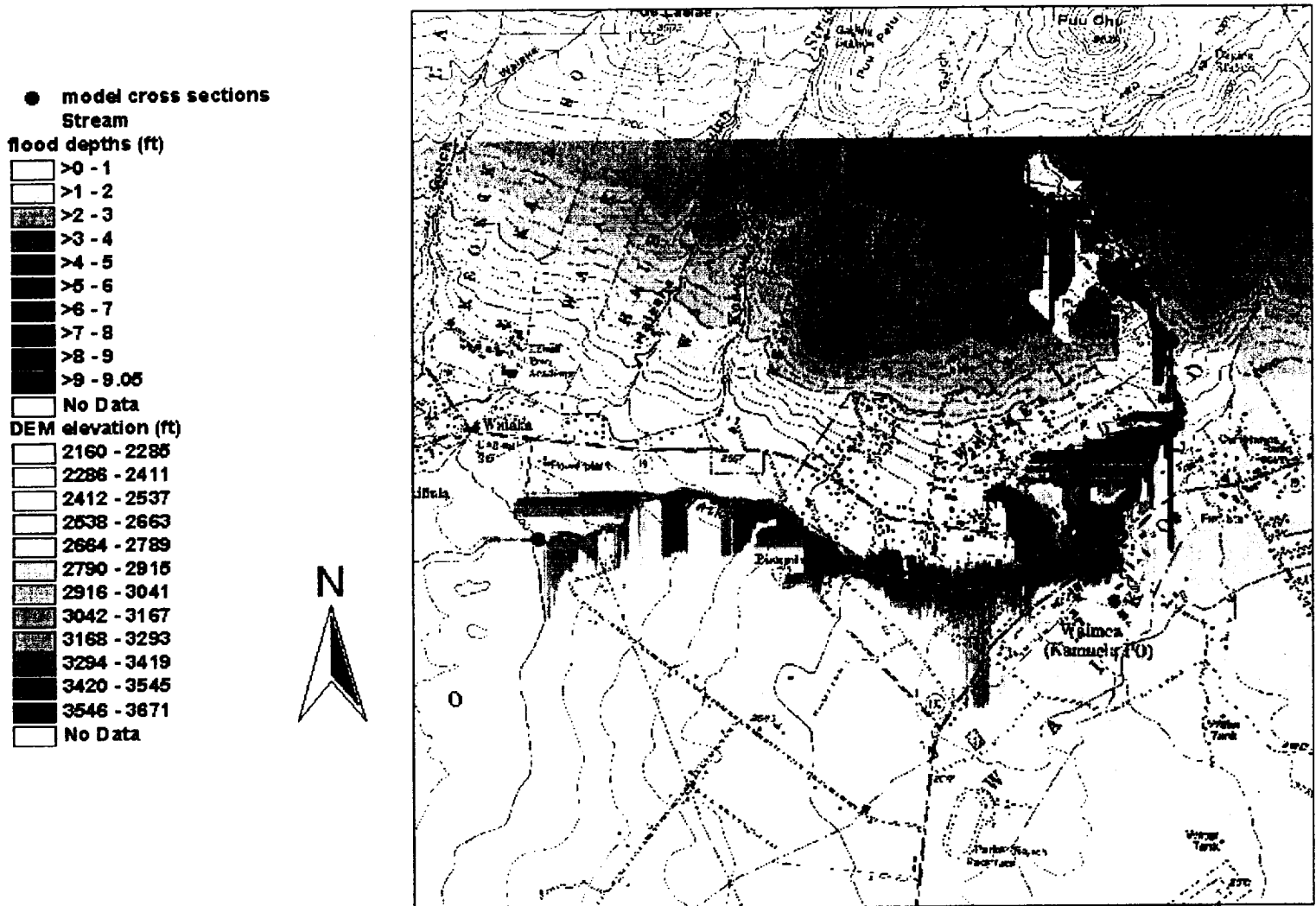
Ground Survey Data

One of the main objectives of the ground survey was to obtain high resolution channel cross sections. The six cross-sections measured in the Waimea floodplain were of particular importance because here the channel capacity is crucial in determining the amount of overbank flooding. The field-measured cross-sections were compared to cross-sections obtained from the DEM. In each of the six locations, the field survey data showed the presence of an inner channel that was absent from the DEM. The DEM appears to be flawed in that it under-represents the amount of topographic relief in the vicinity of the channel. The dimensions of the inner channel are relatively consistent from site to site. On average, it is 9 ft. deep, 16 ft. wide at the bottom, 78 ft. wide at the top, and 26 ft. wide two feet above the channel bottom. Away from the inner channel, the land slopes gently upward and there is general agreement between the DEM and the field survey as to the lay of the land. (There is a vertical offset between DEM elevations and field survey elevations, but this was deemed to be of little importance.)

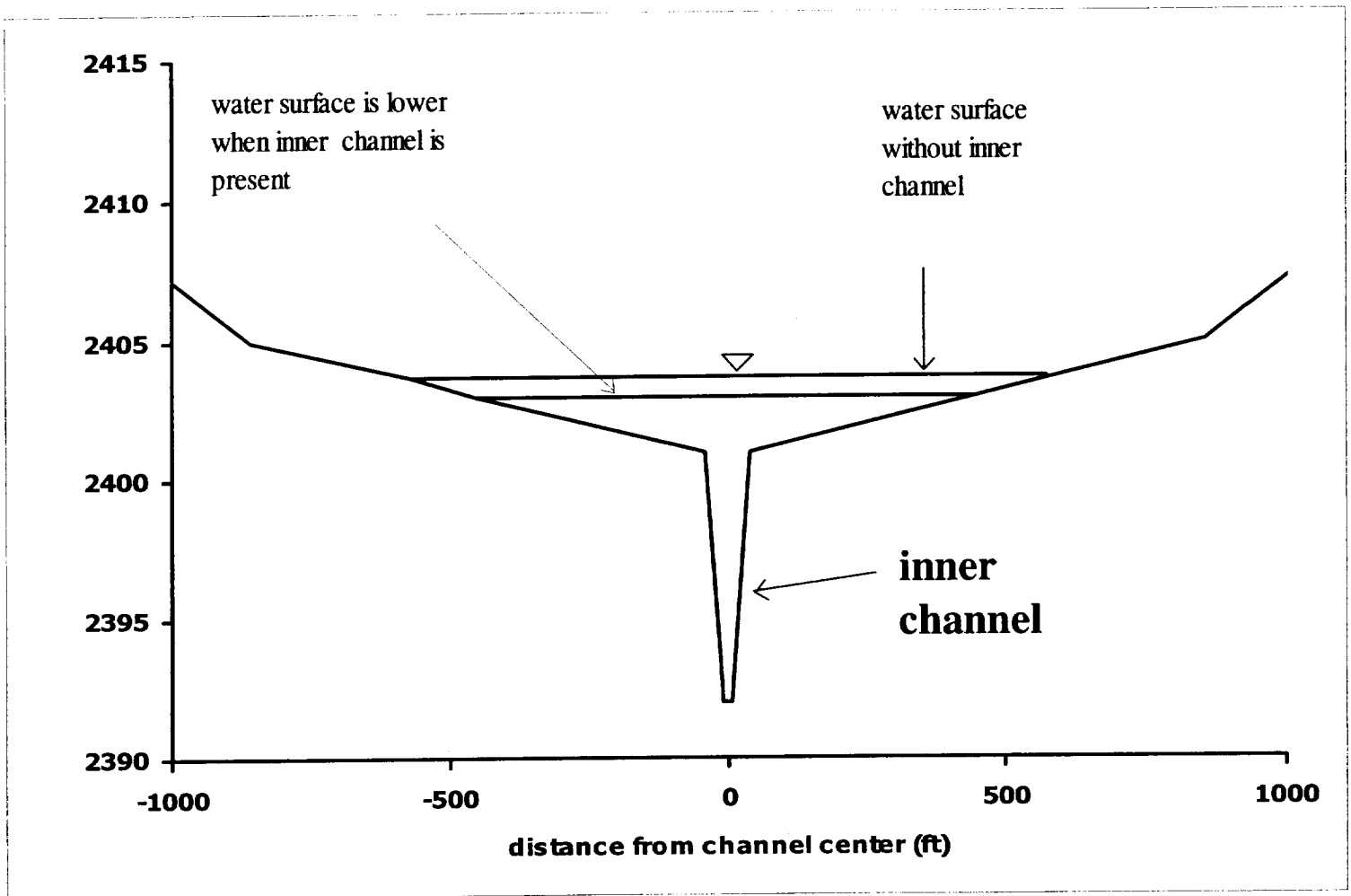
Flood Simulations With and Without Ground Survey Data

If the *FLDWAV* cross-sections are based solely on the DEM, the channel downstream of the Waikaloa Dam will be subtle, and the flood will be broad and shallow. If the *FLDWAV* cross sections are based on the ground survey data, some of the flood will flow swiftly through a relatively deep inner channel. Two simulations corresponding to these two scenarios were conducted (see Figures 3 and 4). In both simulations, a steady 13,000 cfs flood was routed from the dam towards and through Waimea¹. In the first scenario, the channel cross-sections are based only on the DEM. In the second scenario, the channel cross-sections are based on the DEM, but an inner channel is

¹ *FLDWAV* predicts that when the dam is breached over a 15 minute period (the most likely scenario), the flood peak will be about 13,000 cfs when the flood reaches the upper end of Waimea Town. The flood simulations presented in this section are for a steady (time-invariant) flood of 13,000 cfs. A steady flood was used because of numerical instabilities that appeared in the unsteady (flood changes with time) simulations.

Figure 3 - Steady 13,000 cfs with DEM Topography

“carved” into the topography. The dimensions of the inner channel were derived from the ground survey data (see conclusion of previous paragraph for actual dimensions). Special procedures had to be followed when performing the inundation mapping for the second scenario. In the second scenario, the *FLDWAV*-simulated flood depths are measured relative to the bottom of the inner channel (which is about 9 ft. below the DEM elevation). The depth of the inner channel was therefore subtracted from the flood depths prior to performing the inundation mapping. Figure 4 shows the resulting flood



Comparison of simulated floods produced with and without the inner channel (at mile 3.5). Without the inner channel, the flood is 0.66 ft. higher, 27% wider, and 9% slower than when the inner channel is present.

The simulations show that in most sections of the floodplain the addition of the incised channel made the flood slightly faster and slightly reduced the flood elevation. The opposite result was obtained, however, immediately downstream of where the flood debauches from the gulch and begins to spread out over the Waimea floodplain. Flood depths and velocities for specific locations are shown in the following Table. Figure 5 shows the cross-section of the flooded channel.

	Flood Obtained using DEM only	Flood Obtained using DEM plus the inner channel
1.3 miles downstream of the dam (upper end of Waimea Town)	Depth = 4.5 ft Velocity = 5.0 ft/s Width = 1100 ft	Depth* = 4.2 ft Velocity = 5.0 ft/s Width = 1100 ft
1.8 miles downstream of the dam	Depth = 3.6 ft Velocity = 5.6 ft/s Width = 1100 ft	Depth* = 3.4 ft Velocity = 6.0 ft/s Width = 1700 ft
3.56 miles downstream of the dam (after the flood has passed through Waimea Town)	Depth = 2.7 ft Velocity = 8.5 ft/s Width = 1100 ft	Depth* = 2.0 ft Velocity = 9.3 ft/s Width = 900 ft

Summary and Conclusions

The Waimea floodplain contains an inner stream channel averaging about 9 ft. deep and 78 ft wide. This inner channel is not represented in the USGS topographic data, but was discovered by conducting localized field surveys. Failure to represent the inner channel in the *FLDWAV* simulations results in a flood that is slightly higher and slightly slower than would be obtained by using the more accurate topographic data. (This is true for most—but not all—locations within the floodplain.) The improvements obtained by using the more accurate data are modest, at least in this particular case. There is no

* These depths are measured relative to the DEM topography. They do not include the depth of water in the inner channel.

clear answer to the question of whether it is worthwhile to obtain the more accurate and more expensive data. Unfortunately it is difficult to know if the results obtained at the Waikalua / Waimea test site will also be obtained at other sites in Hawaii. Additional testing at several additional sites may shed more light on this issue. Where resources allow, it would be prudent to obtain at least some channel cross-sections from ground surveys. It does not appear to be necessary, however, to use ground surveys to define the channel's longitudinal profile.

SENSITIVITY TO MODEL PARAMETERS

The peak discharge of a dambreak flood is controlled to a significant degree by the breach duration (the time that it takes the breach to form). The breach duration is usually estimated using equations derived from historic dam failures, but it is obviously difficult to predict the breach characteristics for a dam failure that has not yet occurred. To test the sensitivity of the simulated flood to this parameter, simulations were conducted for a 15 minute breach (the best estimate based on available data) and 20 minutes (for comparison). Increasing the breach duration by 5 minutes decreased the flood elevations (at 1.3 miles below the dam) from 4.4 to 4.1 feet, decreased the flood velocity from 5.7 to 4.8 ft/s and increased the time to flooding by 4 minutes.

Of all the *FLDWAV* parameters, Manning's roughness coefficient is one of the most difficult to estimate precisely. Even using the established guidelines it would be quite possible to make Manning's *n* estimates that are off by 25%. Simulations were therefore conducted using two sets of the Manning's *n* values. The first set consists of the original estimates of 0.04 (meadow and floodplain) and 0.07 (forested gulch). The second set of values is 25% higher. Increasing the roughness coefficient by 25% decreased the flood velocity (at 1.3 miles below the dam) from 5.7 to 4.6 ft/s, increased the flood depth from 4.4 to 4.7 ft., and increased the time to flooding by 1 minute.

CONCLUDING REMARKS

There are a large number of assumptions, parameter estimates, and data choices that go into the production of a flood inundation map. In the Waikalua test case, we have seen that each simplifying assumption or uncertain parameter estimate introduces only

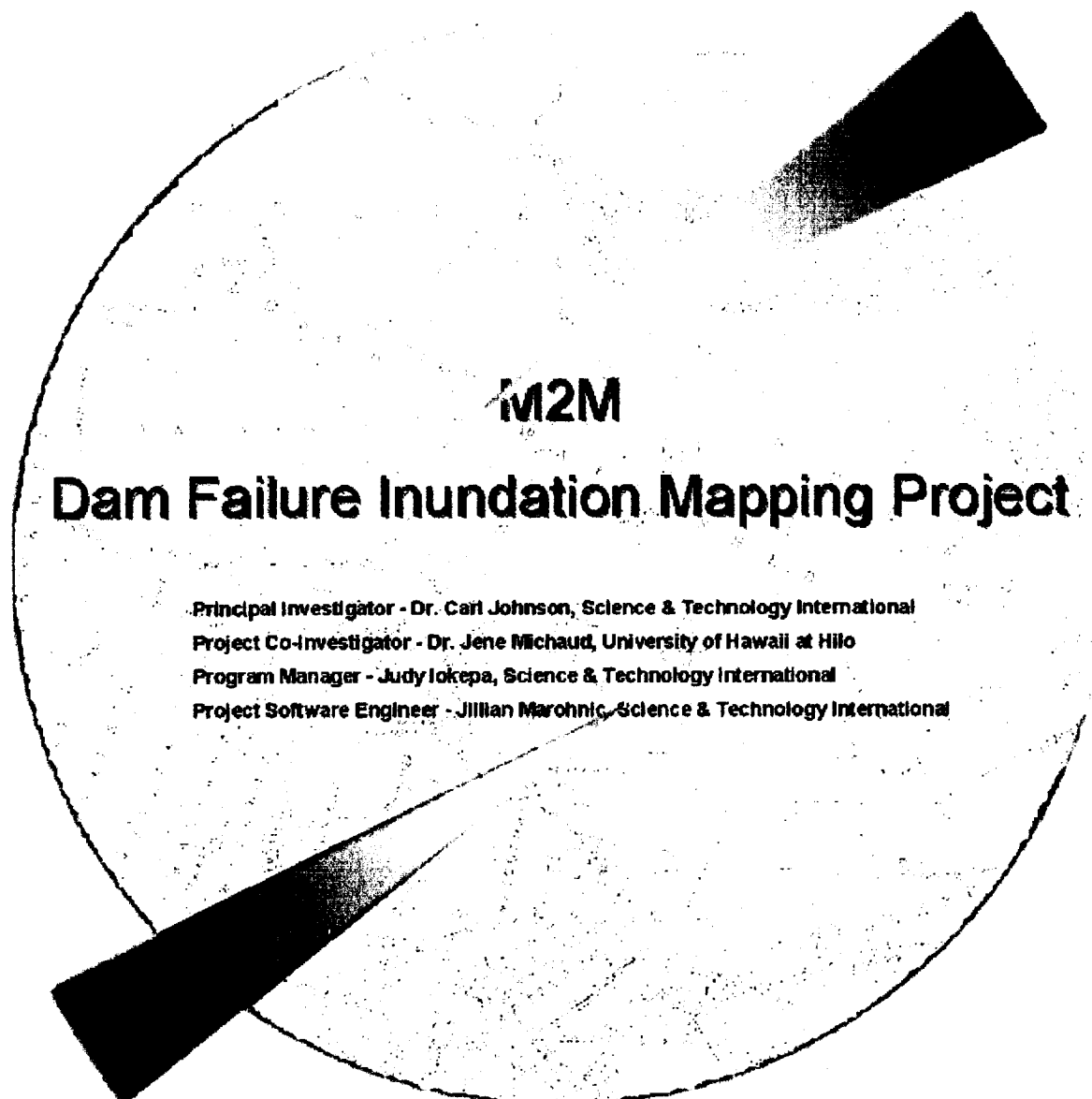
a modest amount of uncertainty into the final inundation map. In all the flood scenarios presented above, the bottom line was the same: a dam break would flood much of Waimea with very short notice. Cars on the highway would be swept downstream, but the flood would recede quickly. For overall planning and warning purposes, it may not matter much if the flood is 3 ft. deep or 4 ft deep. On the other hand, if an inundation map is released to the general public, the assumptions, parameter estimates, and final results will be subject to considerable scrutiny.

It should be noted that it is actually rather difficult to establish error bars on the final inundation maps. This is because while the uncertainty in the flood resulting from uncertainty in one parameter can be evaluated, there are dozens of parameters, and the simultaneous effect of uncertainty in all of them is not easily assessed. This is a problem common to complex, spatially distributed models. It should also be noted that the reassuring results from the Waikaloa test case are of course conditioned on the particular topographic and hydraulic conditions encountered at this particular site. Sensitivity could always be greater—or lesser—at a different site.

Appendix C: User's Guide

BETA RELEASE

M2M



Principal Investigator - Dr. Carl Johnson, Science & Technology International

Project Co-Investigator - Dr. Jene Michaud, University of Hawaii at Hilo

Program Manager - Judy Iokepa, Science & Technology International

Project Software Engineer - Jillian Marohnic, Science & Technology International

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M2M

Dam Failure Inundation Mapping

User's Guide

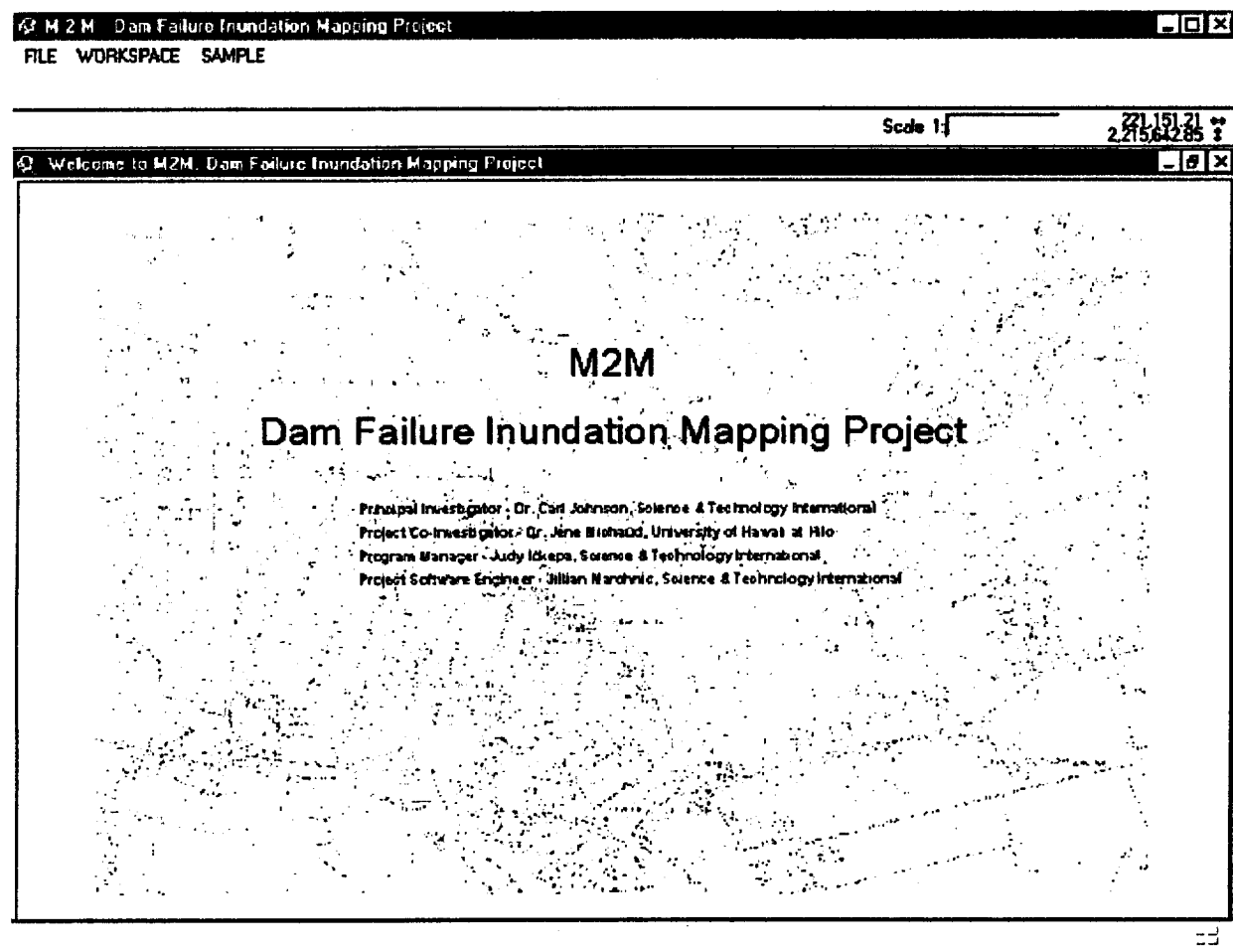


Figure 1: M2M Main Window

Overview

M2M provides a bridge between the National Weather Service's FLDWAV models and the powerful capabilities of the ArcView Geographic Information System. By translating the FLDWAV output into an ArcView grid, or map, the M2M application transports the user from a textual context to a spatial context, providing a visual representation of the flood waters, and thereby facilitating further analysis of the flood's impact.

System Requirements

Software: M2M is an ArcView application, requiring ArcView GIS 3.2 and the Spatial Analyst Extension 2. M2M also depends on the Dialog Designer and Report Writer extensions, supplied with the ArcView 3.2 software. To support its full functionality, M2M requires the National Weather Service's FLDWAV, FLDGRF, and FLDINP models. The latest releases of these models are obtainable, at no cost, from the site <http://hsp.nws.noaa.gov/oh/hrl/rvrmech/fldwav5.htm>.

Special Note: Freeware extension **Basin1** should not be added to the M2M project, because it replaces the project startup script, and effectively disables M2M.

Computer: Being an ArcView GIS 3.2 application, M2M requires an industry-standard personal computer with at least a Pentium or higher Intel-based microprocessor and a hard disk.

Memory: 24 MB RAM (32 MB recommended).

Operating System: Windows 95/98/2000 and Windows NT 4.0. M2M has been tested on Windows NT and Windows 2000.

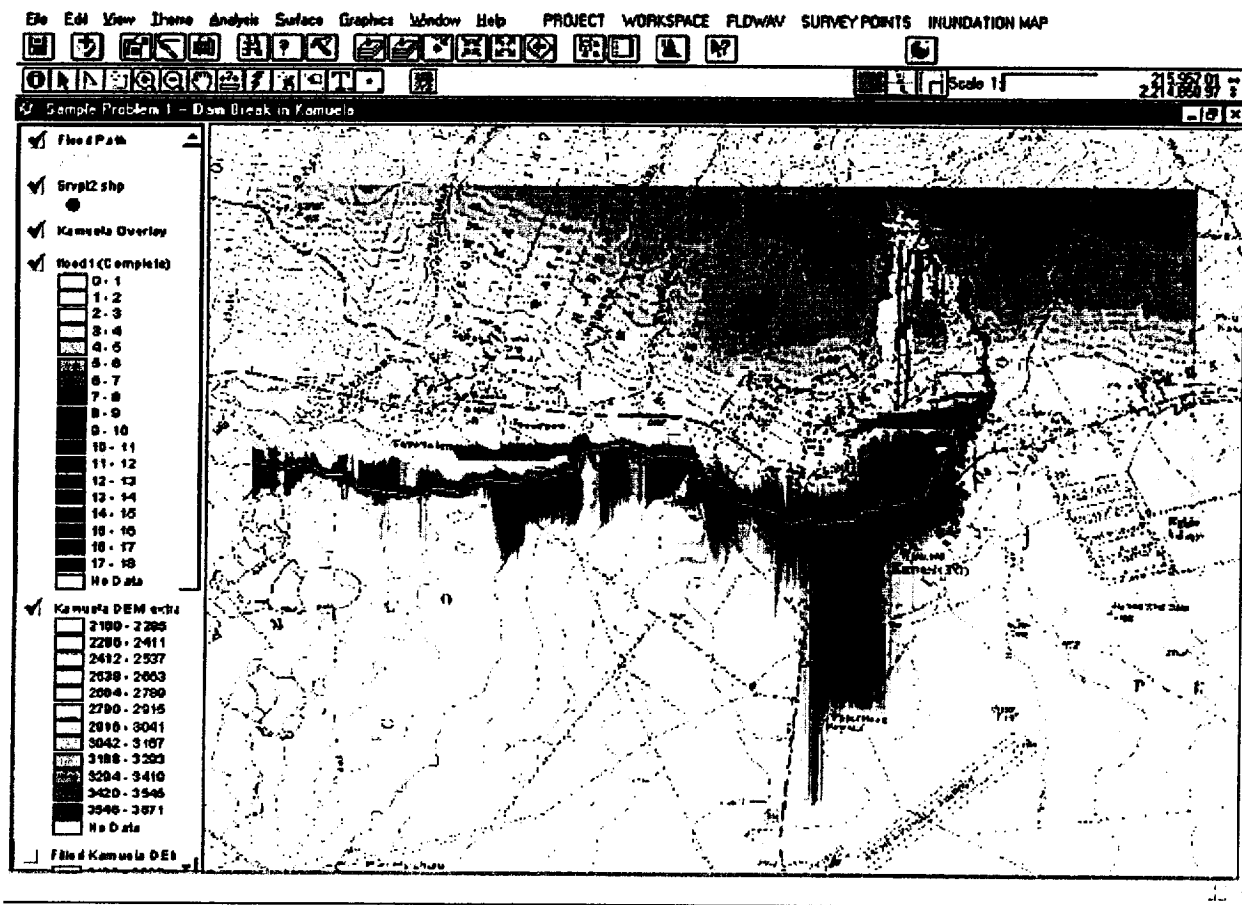


Figure 2: M2M Workspace

Functionality Overview

The user works within the context of an M2M “Workspace” (see Figure 2), which is an ArcView “View” document with a customized menu and tool bar. The Workspace functionality includes all the original View functionality, and provides the additional capabilities of:

- Convenient interfaces to the FLDWAV, FLDGRF, and FLDINP models.
- Tools for mapping survey points onto flood paths, providing the survey point eastings and northings, and distance along stream from dam.
- Tools to aid in preliminary assessment (prior to survey results coming in) by extracting survey point elevation and stream bed cross-sectional data from a Digital Elevation Model (DEM).
- Functionality to facilitate the importing, cropping, and filling of DEMs.
- Production of an Inundation Map, using the FLDWAV “Profile of Crests and Times” output, in conjunction with the underlying DEM and vector representation of the flood path.
- Classification of the flood waters into varying depth and color intervals for easy visual assessment of flood criticality.
- Capability to export the extracted FLDWAV output to an Excel spreadsheet or other report format.

Data Requirements

The following data are required for the proper production of the inundation map:

- A United States Geological Survey (USGS) 7.5 minute (10m) DEM of the study area. A 7.5 minute DEM is terrain elevation data in a digital raster format, 10- by 10-meter data spacing, cast on a Universal Transverse Mercator (UTM) projection. A full description of this format resides at the website <http://wa-node.gis.washington.edu/~uwlib/10mdem.html>. DEMs can be ordered from Earth Science Information Centers, listed at http://mapping.usgs.gov/esic/esic_index.html.
- A USGS 7.5 minute quadrangle Digital Raster Graphic (DRG) of the study area. A DRG is a scanned image of a USGS standard series topographic map, fit to the UTM projection. A full description of this product resides at <http://mcmcweb.er.usgs.gov/drg/>. DRGs, like DEMs, can be ordered from Earth Science Information Centers, and there are many available online, at no cost, from the GIS Data Depot, at <http://www.gisdatadepot.com/catalog>. The DEM and the DRG must be projected into the same UTM zone.
- Site visit data: Field survey data of the stream cross-sections at chosen points along the flood path. Description of the dam to include type, hydraulic height, and surface area when at maximum capacity. Assessment of the type and condition of vegetation in the vicinity of the stream, for determining Manning's n values.

Inundation Mapping Process Walk-Through

This section walks the user through the inundation mapping process.

Follow the italicized instructions to create your own inundation map, using the supplied sample files. Before proceeding, make a copy of the M2M directory for safekeeping.

The use of the M2M menus, buttons, and tools are discussed in greater detail in the **User Interface** section of this guide. Details on the ArcView menus, buttons, and tools can be found by activating the ArcView Help menu, or by reading the ArcView documentation.

Set Up New Workspace

When the M2M application is launched, ArcView 3.2 initializes and then presents the M2M Main Window to the user, as shown in Figure 1.

Using the menu bar at the top of the Main Window (see Figure 3), the user opens a new Workspace.

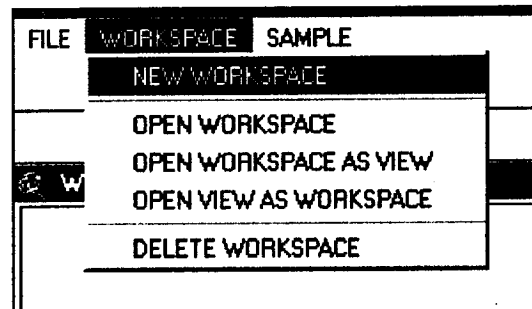


Figure 3: Workspace Menu

When the new Workspace opens, the user is advised that the Workspace's Working Directory is not yet set. The user should do this right away, using the **WORKSPACE/SETUP** option on the menu bar shown at the top of Figure 4. Menu items at the left side of the menu bar belong to the standard ArcView View, while the items at the right, in capital letters, are the menu items unique to the M2M Workspace. The same is true of the buttons and tools.

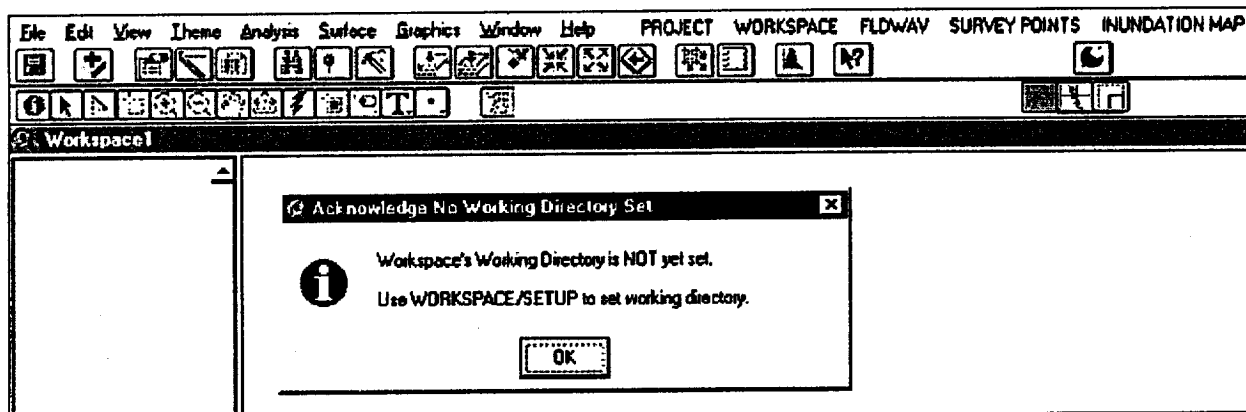



Figure 4: New Workspace

Select **WORKSPACE/NEW WORKSPACE** from the Main Window. When the new workspace opens, click **OK** on the **Acknowledge No Working Directory Set** dialog, then select the **WORKSPACE/SETUP** menu option. When the **Setup for M2M** dialog appears, type in **C:\M2Mtrial** for the Working Directory and **C:\FLDWAV** for the FLDWAV installation directory (or the location of the FLDWAV directory on your machine), then click **OK**.

Prepare Base Map Themes

Once the Working Directory is set, the user should import the DEM of the study area, using M2M's **WORKSPACE/IMPORT DEM** menu option. The user then adds the DRG topographic map, using the **Add Theme**  button or the **View/Add Theme...** menu option. Because the DRG is a TIFF file, the user must select **Image Data Source** as the data source type when the **Add Theme** dialog box appears.

The DRG is useful as an overlay, showing the roads, streams, boundaries, and other features of the study area. To be able to view the underlying DEM, the user should make the background colors of the DRG transparent. Once this is accomplished, the DEM will be visible through the DRG, as in Figure 2. If the DEM appears on top of the DRG, the user can drag its legend box below that of the overlay, to change the stacking order of the themes.

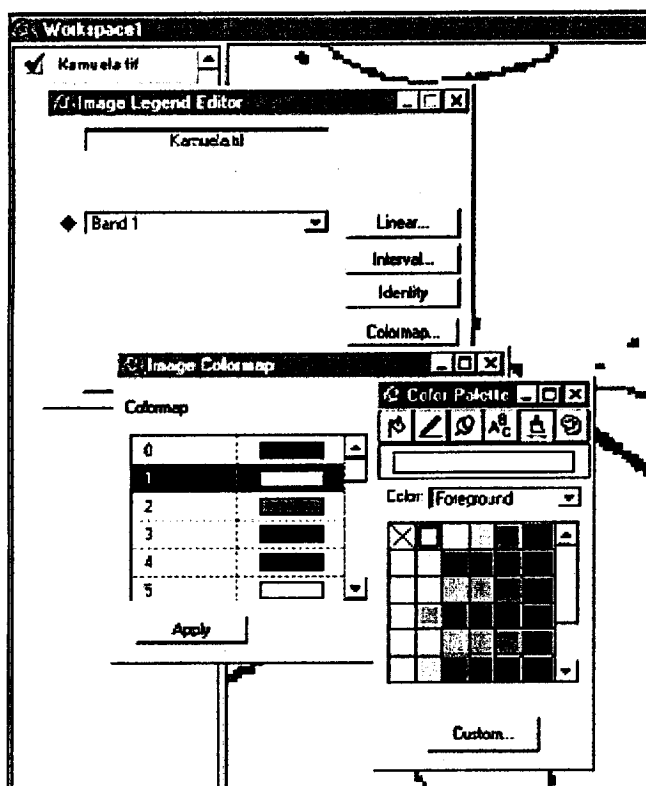






Figure 5: Adjusting DRG Background

From the workspace menu, select **WORKSPACE/IMPORT DEM**. When the **Import USGS DEM Files** dialog appears, navigate your way to the **M2M Samples** directory, select the file **43.dem**, and click **OK**. The next dialog will suggest putting a grid named **dem1** into your working directory **C:\M2Mtrial**. Click **OK** and accept this default. The DEM import operation takes a while, and when it's complete, a theme named **Dem1** will appear in your workspace.

Now click the  button to add the DRG overlay. When the **Add Theme** dialog appears, select **Image Data Source** as the **Data Source Type**, navigate your way to the **M2M Samples** directory, select file **Kamuela.tif**, and click **OK**. When the overlay appears in your workspace, click the checkbox in its legend to make the theme visible. Make the overlay transparent by following the sequence of

steps shown in Figure 5, starting by double clicking on the **Kamuela.tif** legend box, then clicking the **Colormap...** button on the **Image Legend Editor** dialog. When the **Image Colormap** dialog appears, double click on the background colors (first  and then ) , and choose  from the **Color Palette** to make the colormap entry transparent. Click the **Apply** button on the **Image Colormap** dialog to redraw the theme with the transparent colors, and then close the dialog boxes.

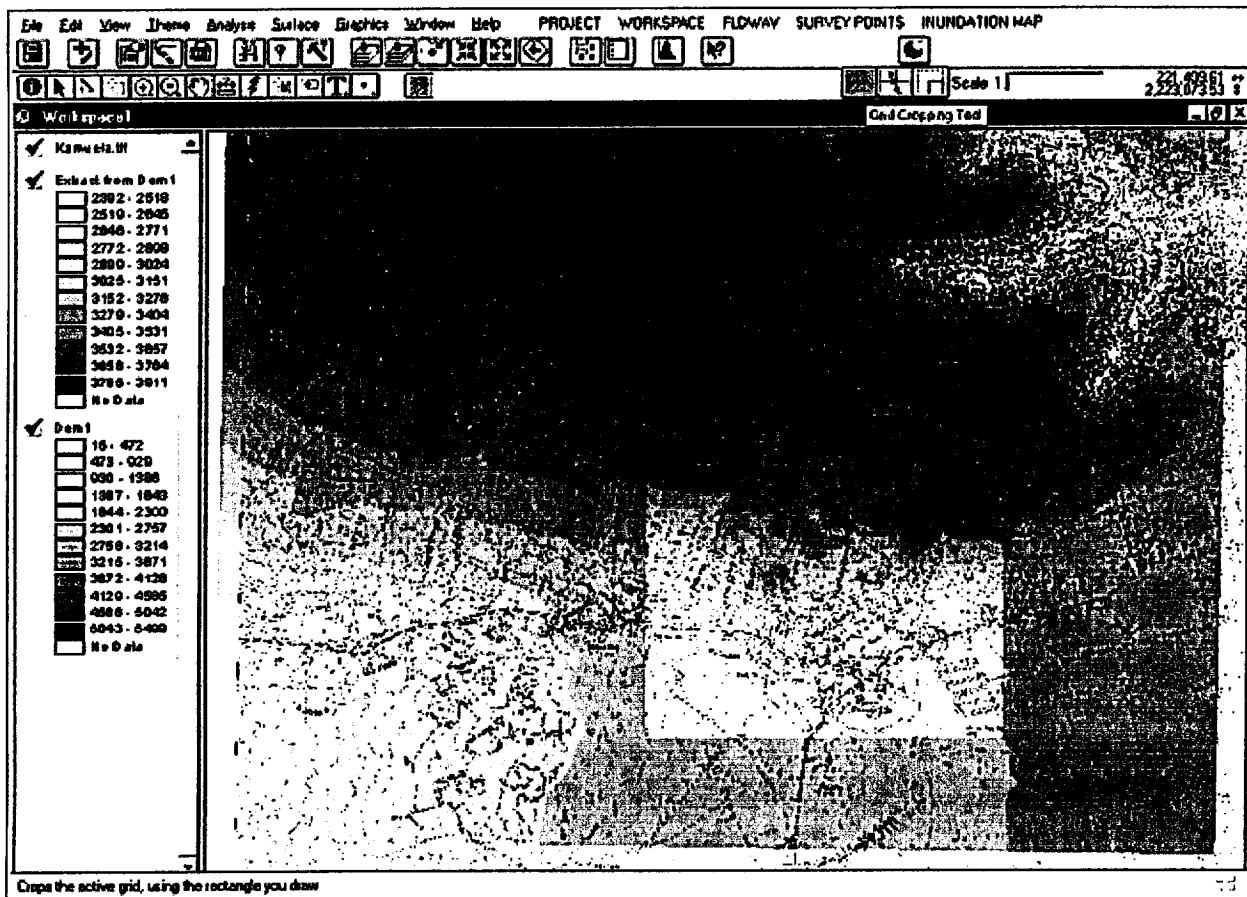











Figure 6: Cropping the DEM

Using the overlay theme for orientation, the user can now zero-in on the study area (using the **Zoom In**  and **Pan**  tools) and crop the DEM to the smallest workable size, using the **M2M Grid Cropping Tool** . It is important that the working DEM extract be as small as possible, so that the time-consuming calculations involving the DEM can operate as quickly as possible. Figure 6 shows a cropped DEM, in orange. To limit screen redraw time, the user should now delete or remove the large DEM, using the **WORKSPACE/REMOVE THEME** or **WORKSPACE/DELETE THEME** menu options, and then set the new area of interest by activating the cropped DEM (click on its legend) and clicking the **Zoom to Active Theme**  button.



Zoom in to the two reservoirs, **Waikoloa Reservoir No 1** and **Waikoloa Reservoir No 2**, by clicking on them with the  tool. Position your view (using  and ) until you can see **Kuhio Village** on the right, **Lanikepu Gulch** label on the left, **Waikoloa Reservoir No 1** on the top, and **Parker Ranch Racetrack** on the bottom. Click on the **Dem1** legend to activate the theme, then click on the  tool. With the crosshairs cursor that appears, click on the view and drag a rectangle around the study area, to include the overlay landmarks mentioned above. As soon as you release the mouse button, the extract operation begins, and an orange grid theme, labeled **Extract from Dem1**, appears in your workspace. If it's not quite right, delete it (by clicking on its legend and then selecting the **WORKSPACE/DELETE THEME** menu option) and try again.

When you are satisfied with the **Extract from Dem1**, delete the **Dem1** theme using the **WORKSPACE/DELETE THEME (Permanent)** menu option. This action will erase **Dem1** from the workspace and then a dialog will appear, entitled **Select dem1 and Delete**. Follow the instructions in the title. When **dem1** is deleted from your disk, click **Cancel** to dismiss the dialog.

The workspace now contains the overlay and the cropped DEM. Click on the cropped DEM's legend to activate the theme, then zoom to the new area of interest by clicking the  button.

Create the Flood Path Theme

The user must now create a theme showing the flood path, or the route of the main body of water when it leaves the dam. Usually the flood path is an existing stream or river on which the dam is built, but this is not always the case.

The DRG topographic overlay shows the streams and rivers in the study area. By tracing over the desired stream in the overlay, the user can create the necessary flood path theme. To do this, the user activates the **View/New Theme...** menu option, and selects **Line** as the feature type for the new theme. When the new theme legend appears, the user selects the **Draw Line**  tool, and traces a stream or river from the topographic overlay, double-clicking to end the tracing. This tracing action should be done without interrupts, so that the polyline formed is one continuous line, and not consecutive line segments. The line can always be refined later, using the **Vertex Edit**  tool.

The flood path should start at the dam, and end where the user intends to locate the final survey point, or stream cross-section. It is important to begin the tracing action at the dam, and not from the opposite direction, as distances from the dam will later be calculated from the origin of the flood path.


If the dam is not located on a river, as in the example in Figure 7a, then the **M2M Water Path**  tool can be used to determine the direction of water flow from the dam break to the river (see the resulting green line in Figure 7b).





Figure 7a: Dam Not On River








Figure 7b: Use Water Path Tool

The user selects the **Theme/Stop Editing** menu option to save the new flood path, or river theme.

*Our example models a break in the earthen dam **Waikoloa Reservoir No 1**, which is not located directly on a stream. Activate the **Extract from Dem1** theme (by clicking on its legend) then click on the  tool. With the bullseye cursor, click on a point at the right edge of **Waikoloa Reservoir No 1**. After several seconds, a green graphic line traces the route of water flowing from that point across the underlying DEM. In the next step, you will use only the portion of this graphic connecting the reservoir to the nearby **Waikoloa Stream**.*

*Now you will create the flood path theme by selecting the **View/New Theme...** menu option. When the **New Theme** dialog appears, select **Line** as the **Feature type**, and click **OK**. The next dialog that pops up suggests a name and location for the new theme. Accept the defaults by clicking **OK**. **Theme1.shp** appears in your workspace legend area, with a dashed lined around the legend check box, which indicates that the theme is in edit mode. The legend symbol is assigned a random color. Double click on the **Theme1.shp** legend to change the color. When the **Legend Editor** dialog appears, double click on the zig-zagged line symbol to bring up the **Pen Palette** dialog box. At the top of the **Pen Palette** dialog, click on the  button to bring up the **Color Palette**. On the palette, select a dark blue, then click the **Apply** button on the **Legend Editor**. The **Theme1.shp** legend should now show a dark blue line. Close the remaining dialog boxes.*

*You are now ready to trace the water route. Click on the  tool. With the crosshairs cursor that appears, trace a line from the reservoir along the green graphic to the **Waikoloa Stream**, along the stream, and over to the left edge of the DEM. Begin by clicking once at the reservoir, then move the mouse and you will see the rubber band line follow. Click again to pin the line to the next point, then continue, clicking down each you have to change direction. To end, double-click, and your dark blue line appears. If you make a mistake, you can delete the line using the **Delete** key on your keyboard, provided the line is selected. If the line is not selected, use the  tool to select it, and then delete it. Once you have a fairly good line, continuous from the reservoir to the left edge of the DEM, you can zoom in on areas of the line and refine it, using the  tool. When you're happy with the line, select **Theme/Stop Editing**, and answer **Yes** when asked whether or not to save the edits. The **Theme1.shp** check box no longer has the dashed line around it, indicating that the theme is not in edit mode. To start editing again, select **Theme/Start Editing**.*

*If your flood path is highlighted (colored yellow), unhighlight it using the  tool. To clear the green graphic water route from the workspace, select it using the  tool, then hit the **Delete** key on your keyboard.*

Plot Survey Points

Now the Workspace contains the cropped DEM, the topographic overlay, and the flood path theme. The next step is for the user to plot the survey points along the flood path, and create a survey points theme.

The survey points are the points along the flood path, or river, for which the user will supply cross-section data to the FLDWAV model. Although the cross-section data should be collected through field surveys, the M2M survey point tools can help to visualize the locations of the points, and can also supply “first-cut” values, extracted from the DEM, for initial model runs. **Appendix B** gives guidance on how to select survey point locations. Note that this step can be skipped if the FLDWAV input or FLDWAV output for the study area already exists.

To plot survey points in the Workspace, the user selects M2M's **SURVEY POINTS / CREATE/EDIT SURVEY POINTS** menu option, then pushes the **Add** button on the **Create Survey Points Theme** dialog (pictured in Figure 12). This brings up the **Add Survey Point** dialog box, shown below in Figure 8.

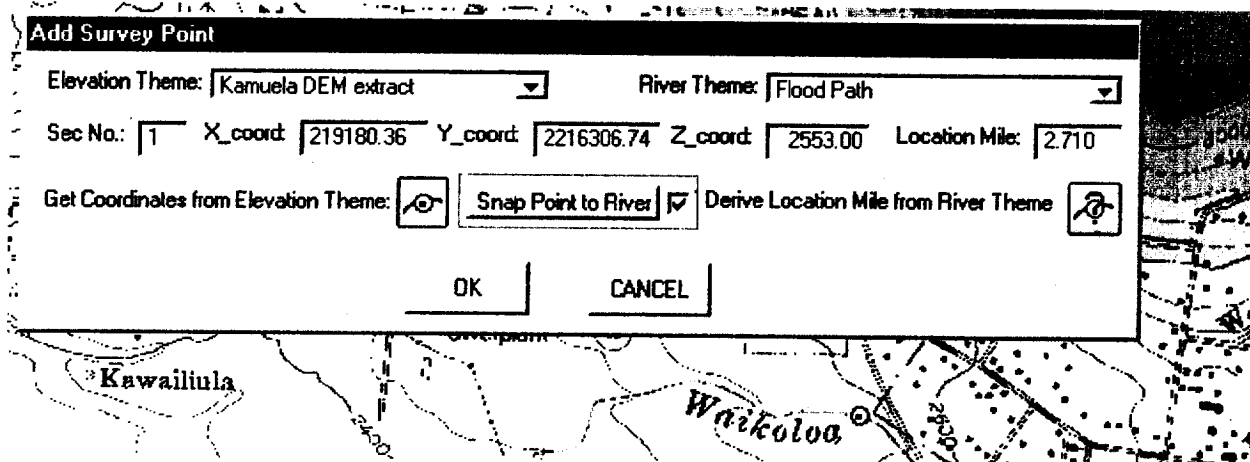






Figure 8: Plot a Survey Point on the Flood Path

With the **Get Coordinates from Elevation Theme**  tool active, the user can click on the Workspace to leave a highlighted survey point (yellow dot  on Figure 8), and to automatically fill in the **X_coord**, **Y_coord**, and **Z_coord** input boxes. The distance of the survey point from the dam (**Location Mile** input box) is filled in when the user clicks the **Derive Location Mile from River Theme**  button. The distance from the dam, and the elevation (**Z_coord**), are values required by the FLDWAV model for cross-section input data.

Another requirement of the FLDWAV model for the cross-section input is the actual cross-section of the channel, or stream, at the survey point. This information can be extracted from the DEM, or from a contour theme, using M2M's **Profile Extractor**  tool (see Figure 9).

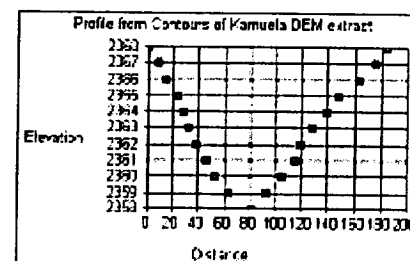


Figure 9: Contour Extract

When all the survey points have been plotted, the user creates the survey points theme by pressing the **Create Theme** button on the **Create Survey Points Theme** dialog. This produces an ArcView point theme, like the one shown in Figure 10, with magenta dots marking the survey points.

If a FLDWAV input file already exists, the user can view the locations of the survey points by clicking the **Import FLDWAV Input** button on the same **Create Survey Points Theme** dialog.

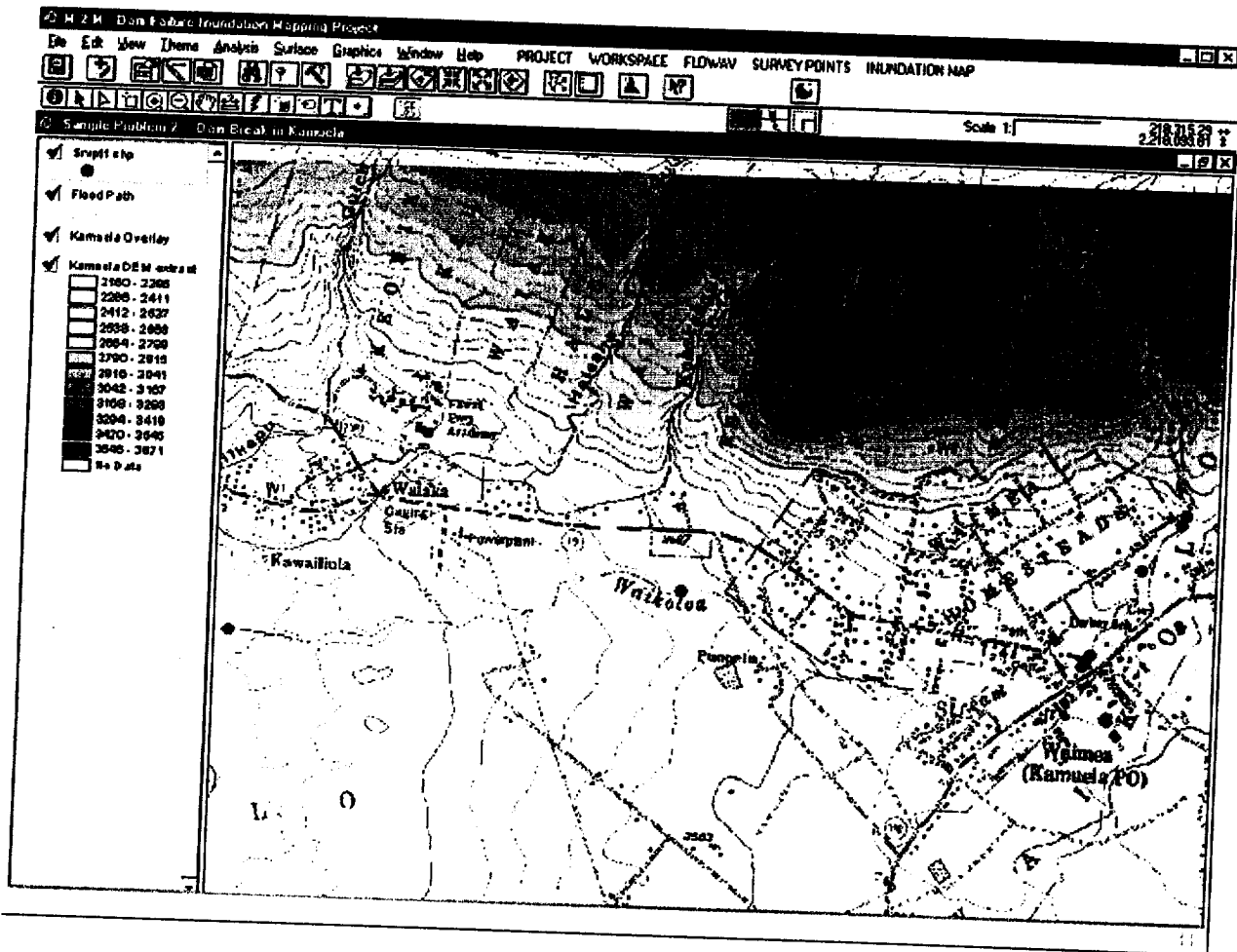


Figure 10: A Survey Points Theme

To view the tabulated survey points data, the user activates the new survey points theme (by clicking on its legend) and then selects the **SURVEY POINTS / SHOW SURVEY POINTS DATA** menu option. This brings up a table of the survey points data, which the user can export to a spreadsheet, or use as a reference while typing into a FLDWAV input file or into the FLDINP input utility.

*In this example, a FLDWAV input file already exists. Select the **SURVEY POINTS / CREATE/EDIT SURVEY POINTS** menu option, and in the resulting **Create Survey Points Theme***

dialog, click on the **Import FLDWAV Input** button. In the **Select FLDWAV Input File** dialog that appears, select *.in for the **List Files of Type**, navigate to the **M2M Samples** directory, choose the file *fplain.in*, which is a text file in FLDWAV input format, and click **OK**. Now a selection box appears asking you to **Select the river theme**. Choose *Theme1.shp* and click **OK**. Another selection box appears asking for the **Elevation Theme**. Choose **Extract from Dem1** and click **OK**. 13 green survey points appear on the workspace, with their data populating the **Survey Points** list box. Click the **Create Theme** button to create a theme from these graphics. The survey points change to a magenta color, and the theme *Srvpt1.shp* appears in the legend.

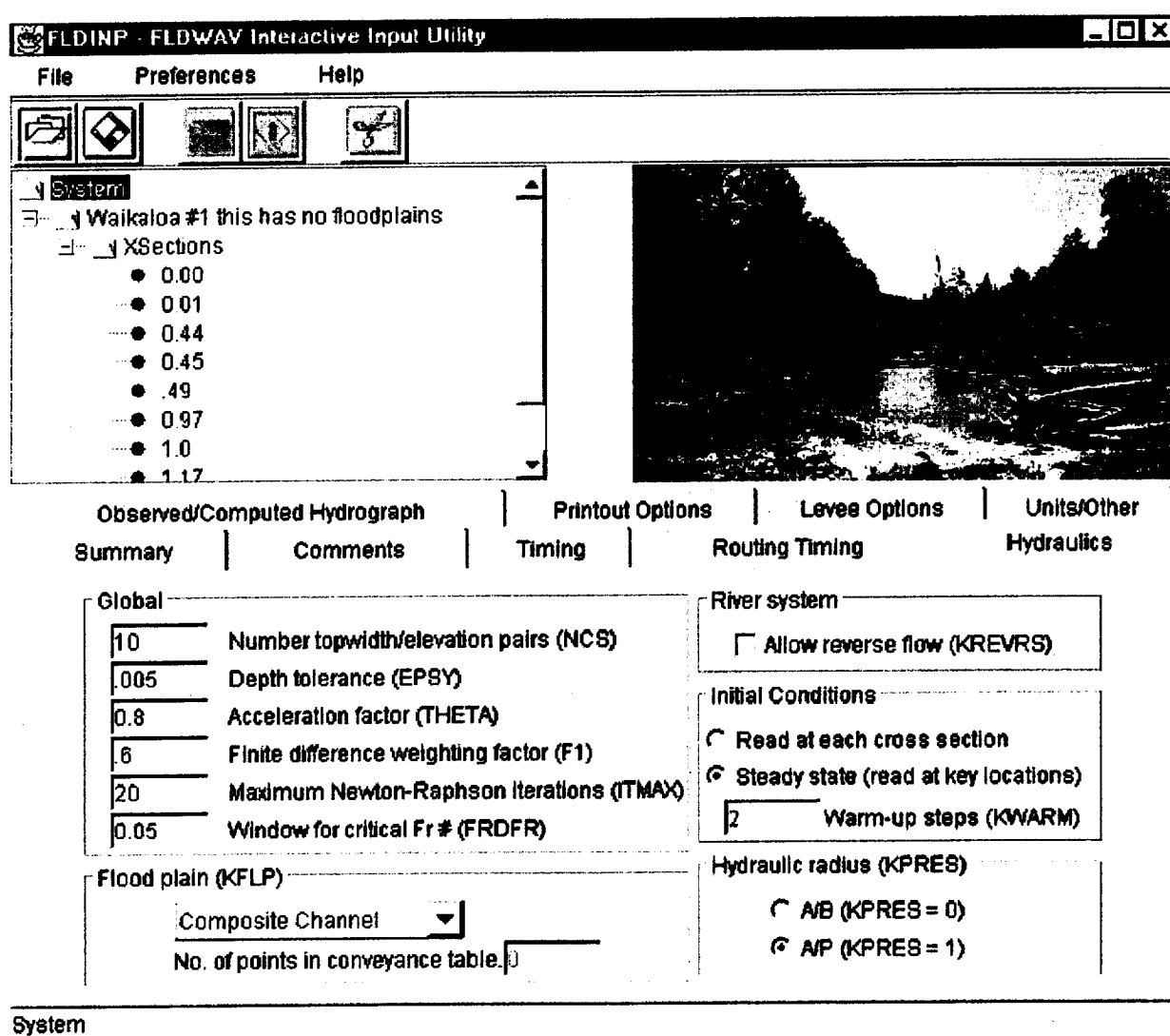


Figure 11: NWS's FLDINP (FLDWAV Input) Utility

Run FLDWAV Model

Once the locations of the survey points have been determined, and the cross-section data have been derived, the user can prepare the FLDWAV input file. If the user is familiar with the FLDWAV input format, the input can be prepared using a text editor. Alternatively, M2M provides an interface to the NWS's new FLDINP utility, which is a user-friendly Java interface for preparing FLDWAV input files. The user activates M2M's **FLDWAV/RUN FLDINP** menu option to bring up the FLDINP interactive input utility, pictured in Figure 11.

When the FLDWAV input file is complete, the user launches the FLDWAV model from M2M's **FLDWAV/RUN FLDWAV** menu option.

*Select the **FLDWAV/RUN FLDWAV** menu option. When the **Run FLDWAV** dialog appears, click the **Select** button next to the **FLDWAV Input File** text line. In the **Select FLDWAV Input File** dialog, select *.in for **List Files of Type**, navigate to the **M2M Samples** directory, choose file *fplain.in*, and click **OK**. Back in the **Run FLDWAV** dialog, your working FLDWAV files directory *C:\M2Mtrail\FLDWAVfiles*, which was created automatically during the workspace setup, appears as the location of your FLDWAV Output File. Type *fplain.out* for the name of the FLDWAV output file, then click the **Run FLDWAV** button. An MSDos command window appears and FLDWAV executes. When the window disappears, the FLDWAV output is complete.*

Import FLDWAV Output

When the FLDWAV model runs, the output is written to a text file. This FLDWAV output must be imported into M2M using the **SURVEY POINTS / CREATE/EDIT SURVEY POINTS** menu option, which brings up the **CREATE SURVEY POINTS THEME** dialog, pictured in Figure 12. The user clicks the **Import FLDWAV Output** button, indicates the name of the FLDWAV output file, and waits while M2M reads the text file, locates the "Profile of Crests and Times" section, parses the data, and displays it both in tabular and graphic formats, as shown in Figure 12. The FLDWAV model supplies water elevation output not only at the user-designated survey points (see magenta points in Figure 10), but also at interpolated intermediate points, as evidenced by the many green output points in Figure 12.

When the import procedure is complete, the user clicks the **Create Theme** button to convert the tabular data and green graphics points into an ArcView point theme. The user may notice that the first cross section point, located at the dam, is not included in the survey points output theme. This is intentional, as it should not be present in the subsequent mapping process.

*Select the **SURVEY POINTS / CREATE/EDIT SURVEY POINTS** menu option to bring up the **Create Survey Points Theme** dialog. Click the **Import FLDWAV Output** button, and in the **Select FLDWAV Output File** dialog box that appears, select the *fplain.out* file and click **OK**. When the selection box appears, asking you to **Select the river theme**; choose *Theme1.shp* and click **OK**. When the next selection box asks you to **Select the elevation theme**, choose *Extract from Dem1* and click **OK**. After quite a bit of processing, output*

points numbering from 2 to 419 appear in the **Survey Points** list box, and are plotted in green in the workspace. Click the **Create Theme** button to turn the green graphic points into a theme. The **Srvpt2.shp** survey points output theme appears in the workspace, with the output points now in magenta.

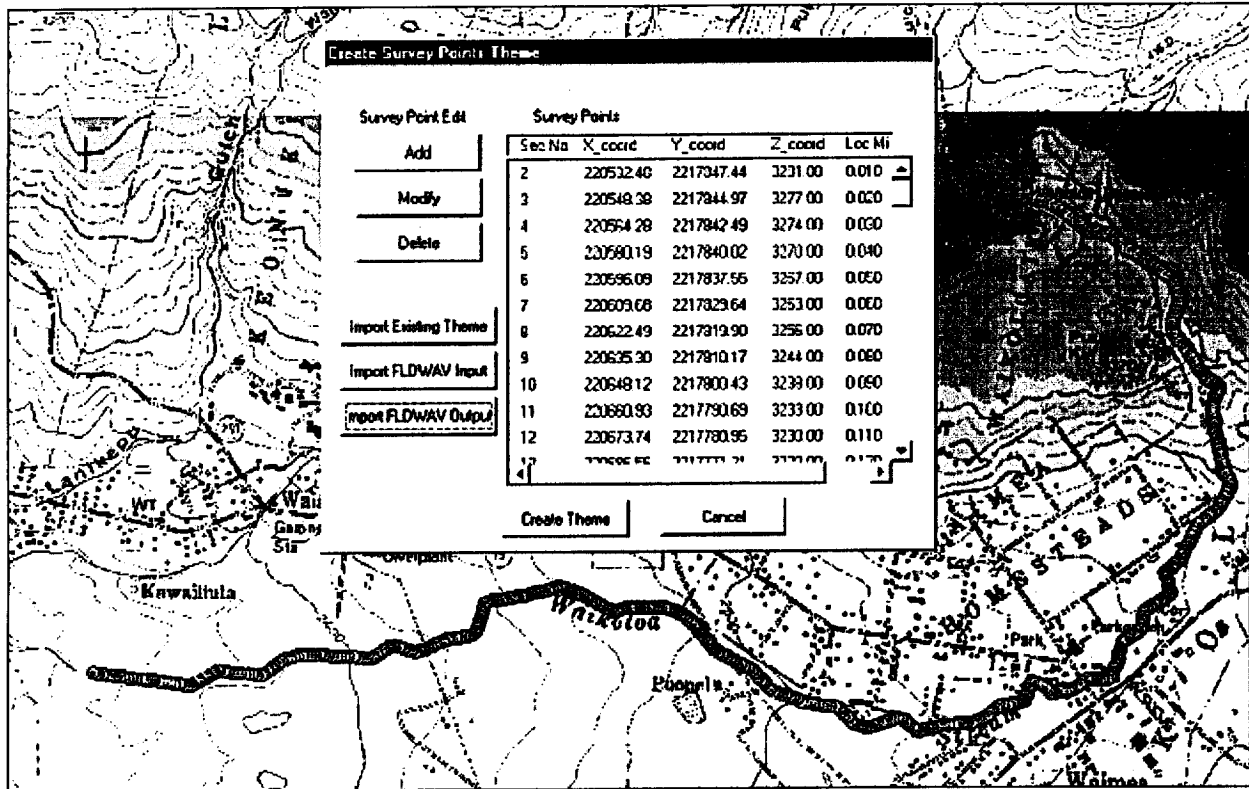


Figure 12: Importing FLDWAV Output

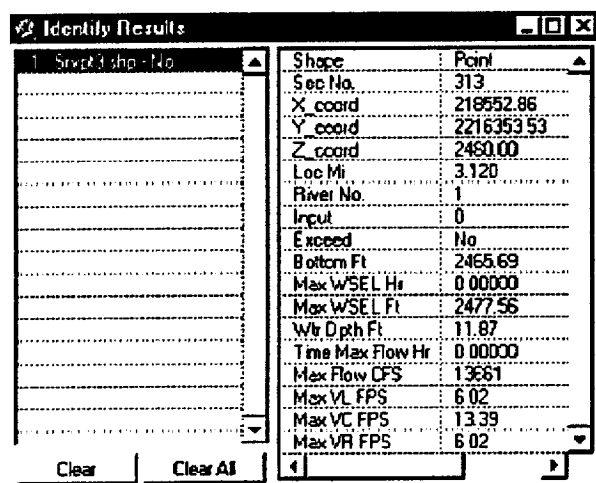



Figure 13: Using "Identify" Tool

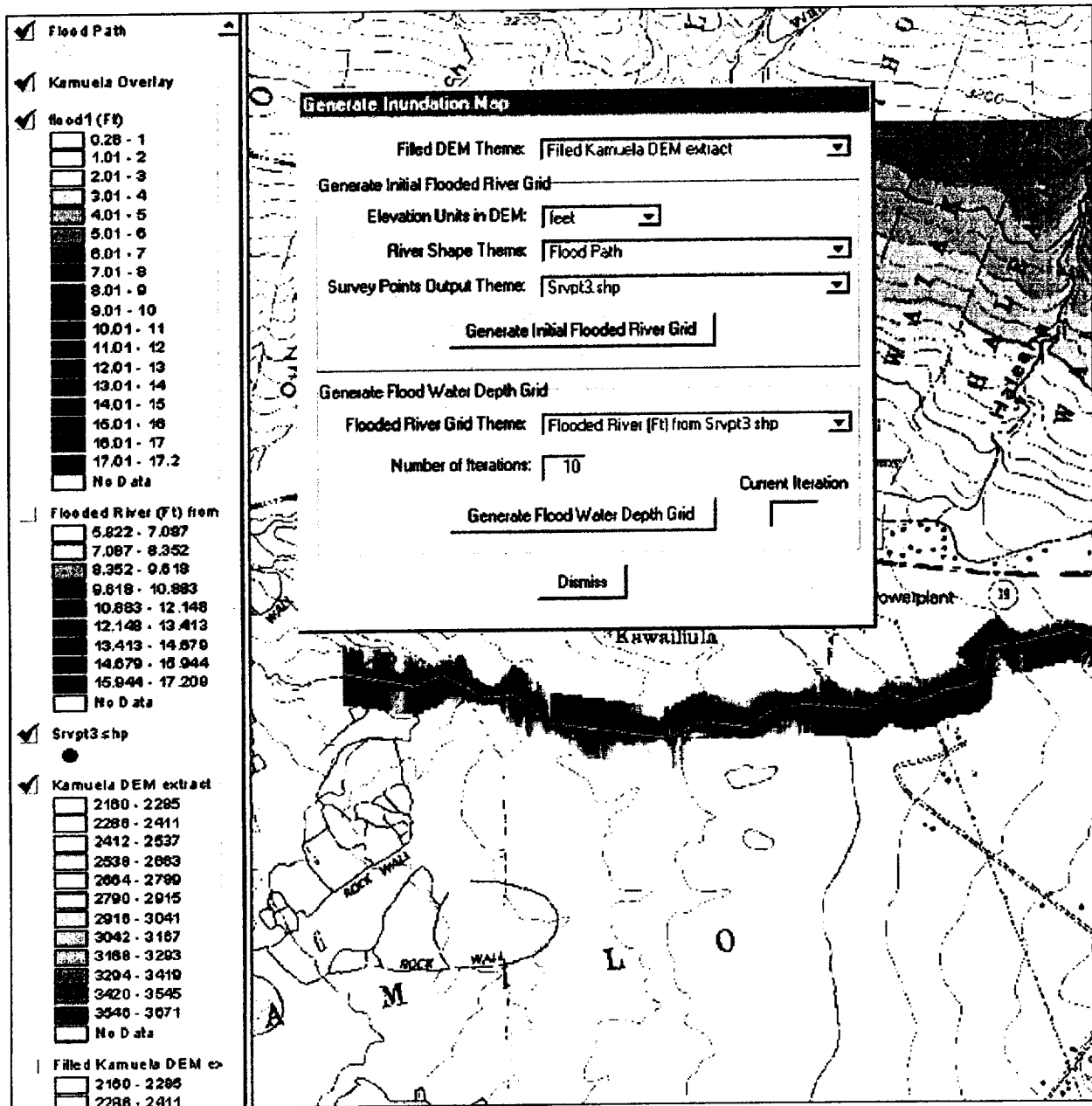
To view the information available at each of the FLDWAV output points, the user clicks on a point with the **Identify**  tool (see results of the **Identify** operation in Figure 13).

To see information on all the points at once, the user clicks on the legend of the new theme and selects the **SURVEY POINTS/SHOW SURVEY POINTS DATA** menu option.

Generate Inundation Map

The generation of the inundation map requires a depressionless DEM, so the first step is to create one from the study area cropped DEM, using the **M2M WORKSPACE/FILL DEM** menu option. This process fills areas of internal drainage in the DEM: areas into which water can flow, but from which there is no outlet.

Now the M2M Workspace should contain the cropped DEM of the study area, the filled DEM, the flood path theme, the survey points output theme, and, optionally, the DRG overlay. The user selects the **INUNDATION MAP/GENERATE MAP** menu option, and is presented with the **Generate Inundation Map** dialog, as pictured in Figure 13.



In the dialog box, the user selects the **Filled DEM Theme**, then fills in the information required for generating the initial flooded river grid. When the top half of the dialog is

filled in, the user clicks the **Generate Initial Flooded River Grid** button, and M2M converts the survey point output theme into a grid depicting the flooded river, interpolating the data between the FLDWAV output points so that each pixel along the flood path has a value, as in the close-up image of Figure 14.

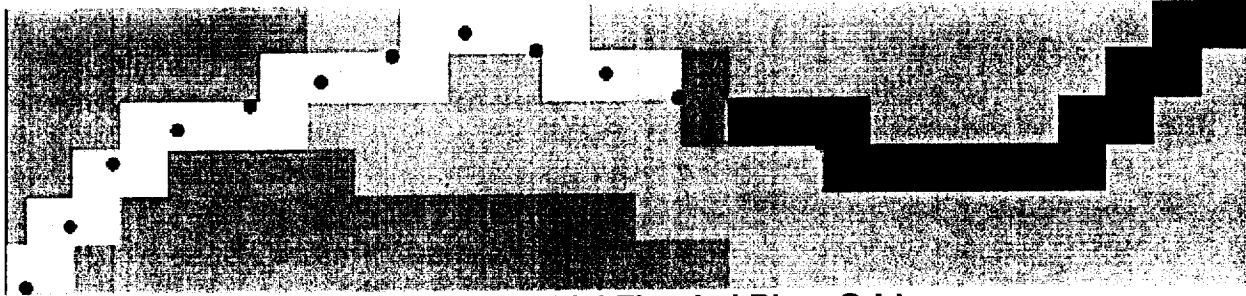


Figure 14: Initial Flooded River Grid

When the initial flooded river grid theme appears in the Workspace, the user fills in the bottom half of the **Generate Inundation Map** dialog box, selecting the new theme as the **Flooded River Grid Theme** input, and clicks the **Generate Flood Water Depth Grid** button.

The generation of the flood water depth grid, or inundation map, is an iterative process, generating many intermediate output grids. Figure 13 shows an inundation map after the first 10 iterations (“flood1” in the legend). When the user continues the map, the “flood1” theme will be used as the **Flooded River Grid Theme** input, and the resulting output, after several more iterations, will automatically be named “flood2”. The user continues this process, deleting flood water depth grid themes from previous iterations when they are no longer needed, until the spreading flood waters are shallow enough at the edges to “call it quits”, or until M2M determines that the flood can spread no further. If the flood is complete, M2M will pop up a dialog box asking for the name of the original unfilled DEM, which it will use to calculate the final flood water depth, depressions and all. The final flood water depth grid will have the word “(Complete)” appended to the end of its name, like the one shown in Figure 2.

It is important to note that the inundation map is not a “snapshot in time”; it does not represent the state of the flood at any one time. The inundation map is produced from FLDWAV results for the *maximum water surface elevation* at each of the output points, and so represents the worst of the flood at each geographic point.

*From the workspace menu, select **WORKSPACE/FILL DEM**. When the selection box appears, asking you to **Select the elevation theme (DEM) to fill**, choose **Extract from Dem1** and click **OK**. A grey-scaled grid theme named **Filled Extract from Dem1** appears in the legend area. It is possible that this filled DEM will be exactly the same as the original DEM. Now select **INUNDATION MAP/GENERATE MAP** from the workspace menu, and fill in the top half of the **Generate Inundation Map** dialog that appears. For the **Filled DEM Theme** select **Filled Extract from Dem1**, for the **Elevation Units in DEM** select **feet**, for the **River Shape Theme** select **Theme1.shp**, and for the **Survey Points Output Theme** select **Srvpt2.shp**. Click the **Generate Initial Flooded River Grid** button to generate the theme named **Flooded River (ft) from Srvpt2.shp**. Now fill in the bottom half of the **Generate Inundation Map** dialog, selecting the newly generated flooded river grid as the **Flooded River Grid Theme**. Leave*

the **Number of Iterations** at 10, and click the **Generate Flood Water Depth Grid** button. This produces the first look at the flood, in a theme named **flood1 (Ft)**. Run 10 more iterations of the inundation mapping algorithm by selecting **flood1 (Ft)** as the **Flooded River Grid Theme**, and clicking the **Generate Flood Water Depth Grid** button again. The resulting theme, **flood2 (Ft)**, shows expanded flood waters. Delete the previous flood theme, **flood1 (Ft)**, by clicking on its legend and then selecting the **WORKSPACE/DELETE THEME (Permanent)** menu option. When the dialog appears, instructing you to **Select flood1 and Delete**, follow the instructions, then click the **Cancel** button to dismiss the dialog.

Run as many iterations of inundation mapping as you like, always substituting the newest flood theme as the current **Flooded River Grid Theme** to generate the next flood water depth grid.

There is no need to ever generate another initial flooded river grid during the process of expanding the flood. The **Flooded River (Ft)** from **Srvpt2.shp** theme is no longer needed, and can be deleted.

To close the **Generate Inundation Map** dialog, click the **Dismiss** button.

This concludes the example. To delete your workspace, return to the M2M main window by selecting the **PROJECT/RETURN TO MAIN** menu option. From the main menu, select **WORKSPACE/DELETE WORKSPACE**, choose your workspace from the list presented in the **Delete Workspaces** selection box, and click **OK**. Then, using the tools supplied with your Windows operating system, delete your working directory **C:\M2Mtrial**.

User Interface

This section gives details on the individual controls that make up the M2M user interface. For an overall view of the inundation mapping process, see section **Inundation Mapping Process Walk-Through** in this guide. For details on the ArcView controls, see the ArcView documentation or on-line help.

Before experimenting with M2M, the user is advised to make copy of the M2M directory for safekeeping, as it is possible to inadvertently delete M2M functional components using ArcView controls.

Main Window Interface

The Main Window of the M2M project is pictured in Figure 1, showing the menu bar across the top. The menu options are explained below:

FILE: The FILE menu is for exiting the M2M project.

FILE / CLEAR AND EXIT: The CLEAR AND EXIT option is used to prepare the project file `M2M.apr` for transfer to a new location. This action deletes all documents in the project file (views, workspaces, tables, charts...), then saves the basic project, and exits. If this action isn't invoked prior to transfer of the project file, absolute path references to documents saved within the project file will cause problems when the project is opened in its new location. The user receives a warning when this menu option is invoked, and is given a chance to cancel the action.

FILE / EXIT: Selecting EXIT causes the M2M project to close. The user is prompted to save any changes before the project closes.


WORKSPACE: The expanded **WORKSPACE** menu, pictured in Figure 3, performs operations on the M2M Workspace document. The Workspace is a customized ArcView "View" document, like the one pictured in Figure 6.

WORKSPACE / NEW WORKSPACE: This menu option creates a new, empty, Workspace into which the user is transported. The user is immediately alerted, with a pop-up message box, that the working directory for the new Workspace needs to be set. See **WORKSPACE / SETUP**, under the **Workspace Interface** section of this guide, for instructions on setting the working directory.

WORKSPACE / OPEN WORKSPACE: This option opens a selection box of existing Workspaces from which the user can choose. If the user chooses a Workspace, that Workspace is opened and the user is transported into it. The user is immediately alerted, with a pop-up message box, as to whether or not the Workspace's working directory is set.

WORKSPACE / OPEN WORKSPACE AS VIEW: This options opens a selection box of existing Workspaces. If the user chooses one, the chosen Workspace is converted to an ArcView View, and the user is transported into it.

If the user adds an ArcView extension to the project, like for instance the Hydrologic Modeling extension, that extension's customized menu (Hydro) is added to the menu bar of the View document. In order to make use of this added functionality, the Workspace must be converted to a View document, as discussed above. The separation of Workspace document from View document was done to protect the Workspace customizations, which could be stepped on by other extensions.

WORKSPACE / OPEN VIEW AS WORKSPACE: This option is provided as a reversal of the **WORKSPACE / OPEN WORKSPACE AS VIEW** action. If the user is in a View and wants to convert it back to a Workspace, he should close the View, and the M2M Main Window will reveal itself beneath. If, for some reason, the M2M Main Window cannot be located, the user can always close all documents until only the Project Window remains (see Figure 15). The Project Window menu bar (along the top of the figure) contains the button , which, when depressed, will take the user back to the M2M Main Window.

WORKSPACE / DELETE WORKSPACE: This option presents the user with a selection box of all Workspaces in the project. If the user chooses one, the chosen Workspace is deleted. Themes that were displayed in the Workspace will still be present on the computer disk.

SAMPLE: The **SAMPLE** menu contains only one option, **DISPLAY SAMPLE**, which opens a sample Workspace displaying a completed inundation mapping scenario. The user can recreate this sample by following along in the italicized portion of the **Inundation Mapping Process Walk-Through** section of this guide.

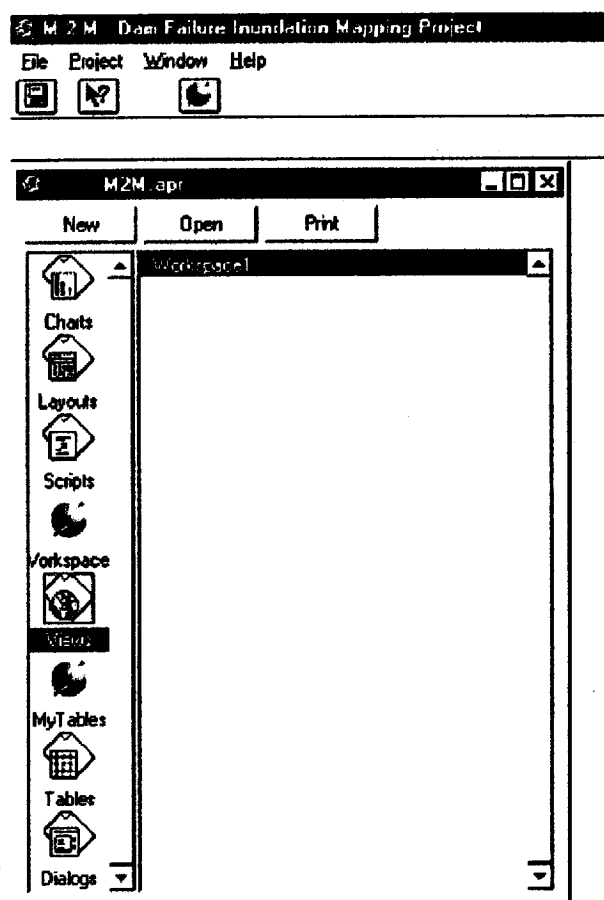


Figure 15: Project Window

Once the user sets the working directory for the sample Workspace, he can experiment with editing survey point themes, creating inundation maps, reclassifying the flood legend, and using the various M2M buttons, tools, and menu options. The sample themes are safe-guarded against deletion with a "read only" status, so, for the most part, the user need not worry about destroying the sample.

Each time the **DISPLAY SAMPLE** option is invoked, the sample Workspace is deleted and then recreated, so that changes by the user do not endure. For this reason, any work the user intends to keep should be done in a Workspace of his own creation.

Workspace Interface

The Workspace menu bar contains the ArcView View menus, tools, and buttons on the left, and the M2M components on the right. M2M menu items appear in all capital letters (see the top of Figure 10). This section discusses the M2M interface components.

Two ArcView menu options important enough to mention here are the **File/Save Project** and **File/Save Project As** options. With these, the user saves changes to project file.

PROJECT: M2M's **PROJECT** menu contains only one item, **RETURN TO MAIN**, which closes the current Workspace and returns the user to M2M's Main Window.

WORKSPACE: Not to be confused with the **WORKSPACE** menu on the Main Window (see **Main Window Interface** section of this guide), this menu provides Workspace setup and management options, and well as DEM manipulation capabilities.

WORKSPACE / SETUP: The **SETUP** option is the first action that the user should invoke upon opening a new Workspace. Many of the other M2M menu items are disabled until the Workspace setup actions have been completed.

The **SETUP** option opens a dialog, pictured in Figure 16, requiring the user to indicate a working directory and the FLDWAV model installation directory.

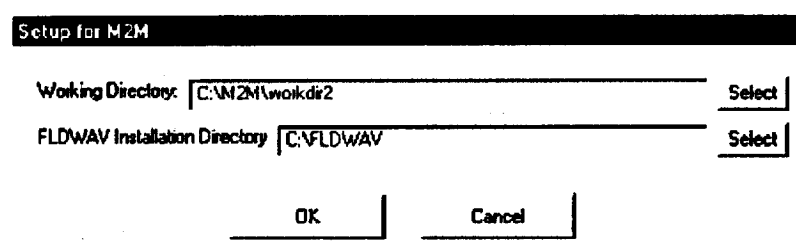


Figure 16: Workspace Setup Dialog

Working Directory: In the **Setup for M2M** dialog, the user selects a working directory by clicking the adjacent **Select** button, and choosing a directory from the resulting file browser. The user can also type in a directory name. If the named directory does not exist, the user will be prompted to create it. The name of the working directory is saved with the Workspace, and is displayed to the user for acknowledgment each time the Workspace is opened. The user can change the working directory at any time by revisiting the **SETUP** option.


The working directory is the place where M2M writes all intermediate working files, and the final results of the various M2M operations. This is also the default directory for any file browsers that M2M opens while the Workspace is active. *The user should not designate an M2M installation directory as a working directory.*

FLDWAV Installation Directory: The directory named as the FLDWAV Installation Directory should contain the FLDWAV executable file, `fldwav.exe`, the FLDGRF executable file, `Fldgrf.exe`, and the two FLDGRF font files, `Modern.fon` and `Roman.fon`.

OK: When the user clicks the **OK** button, M2M creates the working directory, if it does not already exist. It then creates a `FLDWAVfiles` subdirectory, and into it copies the

FLDWAV and FLDGRF executable and font files. This step makes it easier for the eventual locating and filing of the FLDWAV input and output files.

WORKSPACE / REMOVE THEME: The **REMOVE THEME** option removes the active theme or themes from the workspace, after receiving confirmation from the user. A theme is a visual layer in the Workspace's display area. Active themes are those themes whose legend boxes appear 3D, like a button. To activate a theme, the user clicks once on the theme's legend.

When a theme is removed using this method, the theme files are still intact on disk, and the theme can be added back into the Workspace using the **Add Theme**  button.

WORKSPACE / DELETE THEME (Permanent): The **DELETE THEME (Permanent)** option removes the active theme from the workspace, after receiving confirmation from the user. When a theme is removed using this method, the theme is first erased from the Workspace's display area and then its underlying files are erased from disk. It cannot be recovered. If the removed theme is a grid, then a **Source Manager** dialog appears (see Figure 17), giving the user the name of the grid's underlying file structure, and asking the user to select and delete it from the displayed directory. The user should not change directories, as the displayed directory is the one in which the removed theme's

files are located. Once the user has deleted the indicated file, he dismisses the dialog with the **Cancel** button.

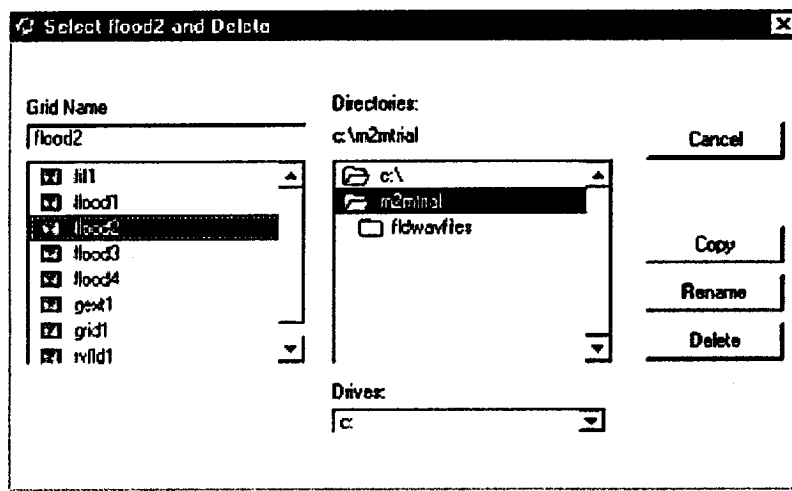




Figure 17: Source Manager Dialog

Grid data structure is complicated, and includes files stored in an **Info** directory. Users should never attempt to rename, delete, or move grid files using Windows tools like "Windows Explorer". Grid files should always be manipulated using the **Source Manager**, called up using ArcView's **File/Manage Data Sources...** menu option.

WORKSPACE / VIEW CHARTS: This option brings up a selection box from which the user can select one or more charts for viewing. These charts are profile extracts, like the one shown in Figure 9, that have been created using M2M's **Profile Extractor**  tool.

WORKSPACE / DELETE CHARTS: The option brings up a selection box from which the user can select one or more charts for deletion. When a chart is deleted, it is removed from the ArcView project, and its underlying data base file is erased from the disk.

WORKSPACE / IMPORT DEM: This menu option enables the user to convert a USGS DEM file to an ArcView grid. Activating the menu option brings up a dialog entitled **Import USGS DEM Files**, within which the user navigates to and selects the DEM file to import. When the selection is made, another dialog pops up, suggesting a default name and location for the output grid file. The default location is the Workspace's working directory, where the user is advised to keep all working theme files.

WORKSPACE / CROP DEM: The **CROP DEM** option pops up a message box, advising the user to activate the DEM (by clicking on its legend), and then use the **Grid Cropping Tool**  at the far right of the tool bar.

WORKSPACE / FILL DEM: This option opens a selection box, from which the user selects an elevation theme (DEM). When the user clicks OK, M2M executes an ArcView procedure that fills depressions, or sinks, in the grid. Sinks are areas into which water could flow, but from which there is no outlet, like a puddle. It is a common procedure to fill DEMs before performing water-based analysis functions. Before using M2M's inundation mapping procedure, the user is required to fill the DEM.

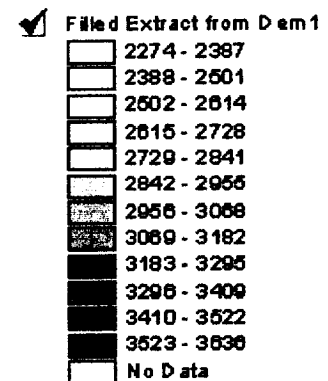


Figure 18: Filled DEM Legend

When M2M creates a filled DEM, the DEM is rendered in shades of grey, and the word "Filled" is prepended to its name (see the sample filled DEM legend in Figure 18). The filled DEM theme is added to the bottom of the legend bar, and it does not come up visible. To view the filled DEM, the user checks the little box next to the theme name.

If the original DEM has no depressions, the filled DEM and the original DEM will be exactly the same.

FLDWAV: The **FLDWAV** menu provides interfaces to the suite of **FLDWAV** models, including **FLDINP**, **FLDWAV**, and **FLDGRF**. Additionally, it provides a link to a text editor, for an alternative means of viewing and editing **FLDWAV** input and output files.

FLDWAV / RUN FLDINP: This menu option brings up a simple dialog (Figure 19), asking the user for the location of the **FLDINP** batch file, `fldinp.bat`. This file is normally in the bin directory, beneath the upper level **FLDINP** installation directory. When the user clicks the **Run FLDINP** button, M2M copies the **FLDINP** gif directory into

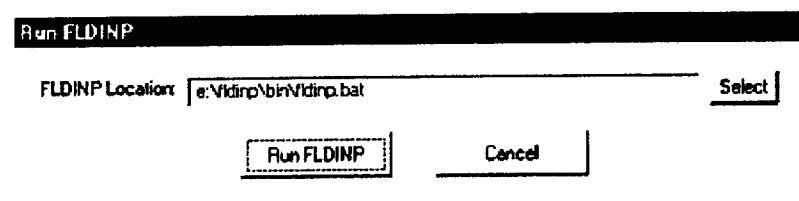


Figure 19: M2M's Interface to FLDINP

the **FLDWAVfiles** subdirectory of the Workspace's working directory (unless it's already there), and then executes **FLDINP** from within the **FLDWAVfiles** directory. This was done so that the default directory for **FLDINP**'s

input and output file dialogs would be the Workspace's working directory, further encouraging users to keep all files related to the Workspace within its working directory.

The FLDINP graphical input utility, pictured in Figure 11, pops up after a couple of seconds, and with it, the user can create FLDINP input files. As of this writing, the FLDINP utility is a beta release, and has some problems, especially with flood plain input, as noted in **Appendix B**. Please contact the NWS (Janice.Sylvestre@noaa.gov) if you have any problems, or view the FLDWAV Update website <http://hsp.nws.noaa.gov/oh/hrl/rvrmech/fldwav5.htm> to check for new releases and/or documentation for FLDINP.

FLDWAV / RUN FLDWAV: This option brings up M2M's interface to the FLDWAV model (Figure 20). The user types in the path to the FLDWAV Input File, or navigates to the file using the **Select FLDWAV Input File** dialog that pops up when the user clicks the adjacent **Select** button. The path to the FLDWAV Output File is automatically filled in as the FLDWAVfiles subdirectory of the Workspace's working directory, and this cannot be changed. The user must type in the name of an output file. If the user plans on running the FLDGRF utility at a later time, the basename of the output file should not exceed 8 characters.

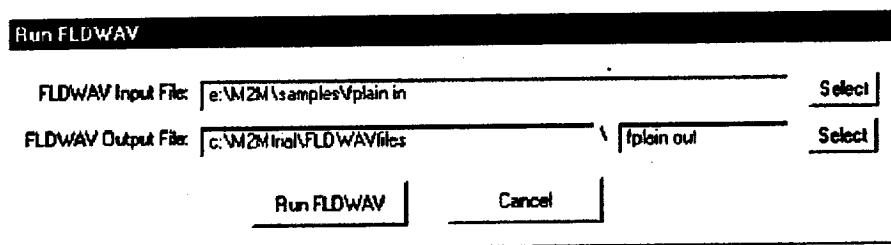


Figure 20: M2M's Interface to FLDWAV

When the user clicks the **Run FLDWAV** button, M2M copies the specified input file into the Workspace's FLDWAVfiles subdirectory, and then launches the FLDWAV model.

The output from the FLDWAV model consists of 18 files, named using the basename and 18 different extensions. All of these files are binary, except for the user's specified output file, which is a text file, and which is the file that M2M will read during the creation of the survey points output theme. The binary files are used by the FLDGRF utility.

FLDWAV / VIEW/EDIT FLDWAV FILES: The user can view FLDWAV input and output files using this menu option, which brings up a text editor interface, as shown in Figure

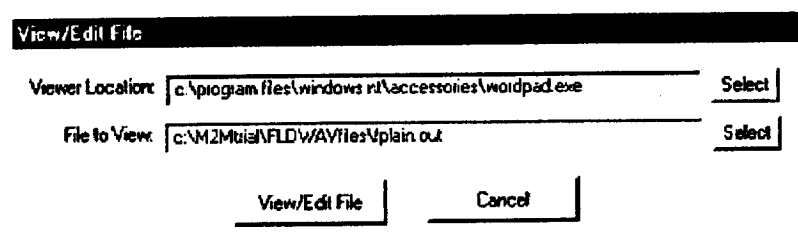


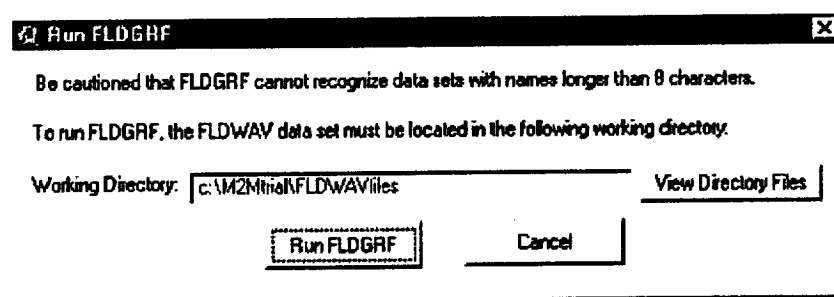
Figure 21: Text Editor Interface

21. The user fills in the **Viewer Location**, which should be a simple text editor, like Notepad or Wordpad, that doesn't insert any formatting characters into the text. The path to Wordpad, on Windows NT and Windows 2000, is C:\program

files\windows nt\accessories\wordpad.exe. The user fills in **File to View**, which should be the text file input or output file from FLDWAV, and then clicks the **View/Edit File** button.

Descriptions of FLDWAV input and output files are given in great detail in the FLDWAV documentation, which is generally included with the FLDWAV installation package.

FLDWAV / RUN FLDGRF: The RUN FLDGRF menu option brings up an interface to the FLDGRF model (see Figure 22). The **Working Directory**, where FLDGRF will look for the input files, is filled in automatically as the Workspace's working directory, and this cannot be changed. There is nothing for the user to do, except to be prepared with the "data set" name which FLDGRF will request when it executes (see Figure 23, left side). To view the data choices prior to launching FLDGRF, the user can click the **View**



Directory Files

button for a view of the working directory files. The "data set" name is the basename (file name without extension) of the 18 FLDWAV output files. FLDGRF cannot handle data set names greater than 8 characters.

Figure 22: M2M's Interface to FLDGRF

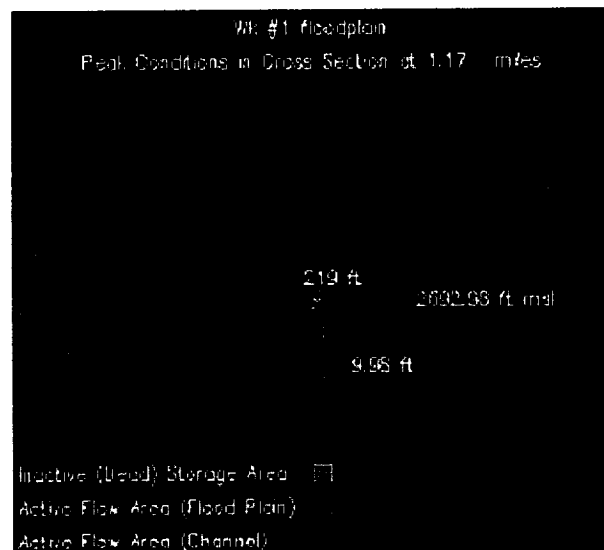
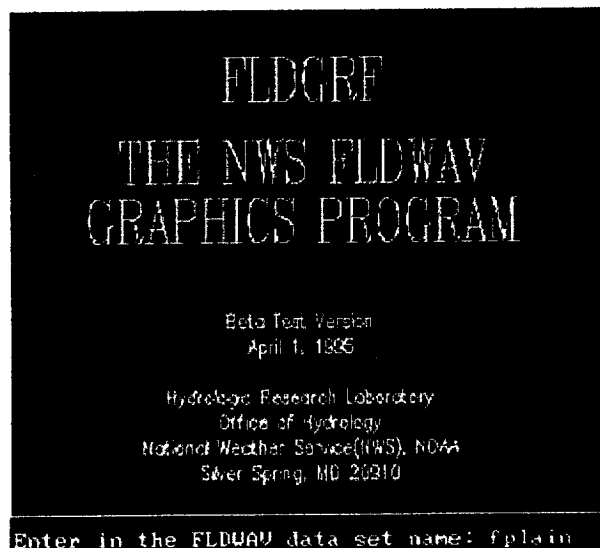




Figure 23: NWS's FLDGRF Utility (Main Screen & Cross-Section View)

To dismiss any of FLDGRF's views, the user hits the Enter key on the computer keyboard. To move from an active FLDGRF session back to the Windows environment, the user hits the  key on the keyboard, and to return to the FLDGRF session, the user hits the DOS command window icon  on the Windows status bar.

SURVEY POINTS: The **SURVEY POINTS** menu provides the user the capability to map survey points onto the Workspace display. Tools are provided for creating survey point themes from scratch, or through the importation of FLDWAV input and output files.

SURVEY POINTS / CREATE/EDIT SURVEY POINTS: This menu option brings up the **Create Survey Points Theme** dialog box pictured in Figure 12. The dialog button functions are described below.

Add: The **Add** button enables the user to plot a survey point graphic in the Workspace. Before clicking the **Add** button, the user is advised to have a DEM and a DRG topographic overlay theme visible in the Workspace.

If the user is adding the very first survey point of the dialog session, M2M asks whether to use Kilometers or Miles (see Figure 24) for the distance calculations. Both units of measure are accepted by the FLDWAV model.

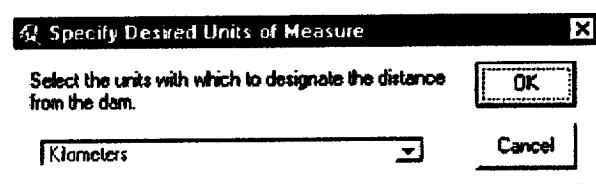



Figure 24: Specify Distance Units

Clicking the **Add** button brings up the **Add Survey Point** dialog (pictured in Figures 25 and 8 showing different distance units). The user selects the **Elevation Theme** and **River Theme** using the dialog's combo boxes: the available selections are only those themes present in the Workspace.

M2M automatically fills in the **Sec No.** box (an identifier used by the FLDWAV model) with the next available integer. The user can change this number if so desired.

The user fills in the **X_coord**, **Y_coord**, and **Z_coord** input boxes either by typing or by using the **Get Coordinates from Elevation Theme** tool. To use the tool, the user clicks on

, and with the resulting bullseye cursor clicks on the Workspace display area, at the point where the survey point

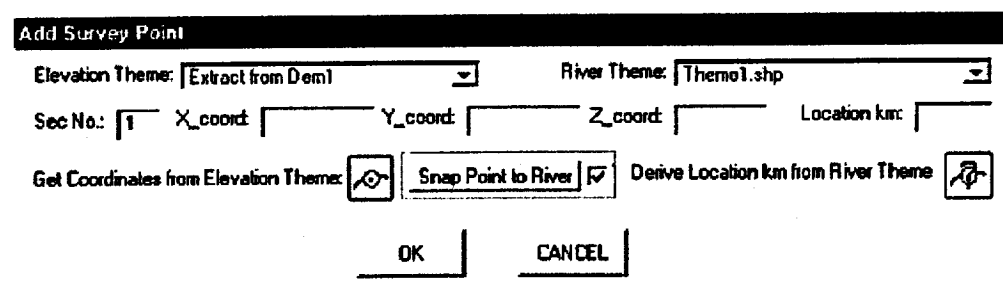


Figure 25: Add Survey Point Dialog (showing Km as distance units)

should be plotted. To help position the point precisely on the river (or flood path), the user can check the **Snap Point to River** check box prior to positioning the cursor, or, after-the-fact, can click the **Snap Point to River** button.

After the user supplies the **X_coord** and **Y_coord**, either by typing them in or by using the tool, a highlighted graphic point on the Workspace display shows the point's location. The user can move this graphic either by retyping the coordinates or by clicking in a different spot with the bullseye cursor.

To fill in the **Location km** (or **Location Mile**) input box, the user either types in the information or derives it from the named **River Theme** by clicking the **Derive Location km from River Theme** (or **Derive Location Mile from River Theme**) button. The **Location km** is the survey point's distance, along the river, from the dam.

The river theme (or flood path theme) referred to in the dialog is a theme created by the user, beginning at the dam and following the water path down to the final survey point. Instructions on creating this theme are given in the **Inundation Mapping Process Walk-Through** section of this guide, in the sub-section entitled **Create the Flood Path Theme**.

When the user clicks **OK**, the highlighted survey point on the **Workspace** display turns green, and the survey point data is added to the **Survey Points** list box (see Figure 12) of the **Create Survey Points Theme** dialog.

Modify: When the user clicks on a line of data in the **Survey Points** list box, in the **Create Survey Points Theme** dialog (Figure 12), the associated survey point graphic on the **Workspace** display highlights. To modify a survey point, the user highlights the line of data in the **Survey Points** list box, then clicks the **Modify** button. The **Modify Survey Point** dialog box pops up, looking just like the one in Figure 25 (but with a different title), with the point's current data filled in. The user can change any value by following the instructions above for the **Add** button.

Delete: To delete a survey point, the user highlights the related line of data in the **Survey Points** list box (verifies that this is the correct point by viewing the highlighted survey point graphic on the **Workspace** display) and clicks the **Delete** button.

Import Existing Theme: When this button is clicked, a selection box appears with a list of all survey points themes currently in the **Workspace**. The user chooses one, clicks **OK**, and the theme's survey points are plotted with green graphics on the **Workspace** display area, while the survey points' data fill the **Survey Points** list box of the **Create Survey Points Theme** dialog. Once the theme is imported, the user can add, modify, and delete survey points using the dialog buttons discussed above. When editing is complete, the user clicks the **Create Theme** button, and creates a new theme. The old theme can then be deleted.

Import FLDWAV Input: Before activating this button, the user should have both the river theme and the elevation theme present in the **Workspace**. The river theme is the line theme tracing the flood path from the dam (see section **Create the Flood Path Theme**), and the elevation theme is the **DEM**.

At this time, FLDWAV file imports are limited to those scenarios with only one river.

When the **Import FLDWAV Input** button is clicked, a file dialog appears, from which the user selects a FLDWAV input file. When the selection is made, two more selection boxes appear, the first asking the user to select the river theme, and the second asking for the elevation theme. The themes presented for selection are only those themes currently in the **Workspace**.

In importing the FLDWAV input, M2M opens the input file, reads the flag specifying whether or not the data is metric (FLDWAV parameter METRIC in data group 1), and extracts the cross-section locations (parameter XT in data group 18). M2M uses a cross-section's location value, which is its distance from the dam along the river, to find its location on the river theme (the one selected by the user), and from there to derive its X and Y geographic coordinates. For this reason, the single polyline tracing the flood path in the river theme must begin at the dam, as discussed in the **Create the Flood Path Theme** section.

Once a cross-section's coordinates have been determined, M2M extracts the point's **Z_coord** value from the elevation theme (DEM). M2M does not check to determine whether a survey point's **Z_coord** value matches the elevation specified in the input file for the channel bottom at that cross-section.

The imported cross-sections are assigned consecutive ID numbers (Sec No.) and the data are displayed, line by line, in the **Survey Points** list box of the **Create Survey Points Theme** dialog (Figure 12). At the same time, the survey point green graphic points are plotted in the Workspace display.

If the survey points don't seem to be plotting in the correct place, there are three possibilities that come to mind:

- There could be a problem with the distance units. Check the FLDWAV input file to be sure the METRIC parameter properly reflects the cross-section location values. Ascertain that the DEM is indeed cast on a UTM projection (see **Data Requirements** section), as M2M converts cross-section location values to meters for plotting.
- The cross-section locations (parameter XT) in the FLDWAV input file may simply be off (how were they derived?).
- The river theme may not be accurate. If the user "cut corners" while creating the river theme, the bends in the river might be smoothed, causing the river to be shorter and throwing off the "distance along the river" measurements. Compare the river theme to the DRG topographic overlay, using the **Zoom In** tool, and edit the river theme if necessary (see ArcView on-line help for editing a theme).

Import FLDWAV Output: As with the **Import FLDWAV Input** button, the user should have both the river theme and the elevation theme present in the Workspace before activating this option.

When the **Import FLDWAV Output** button is clicked, a file dialog appears, from which the user selects a FLDWAV output file. When the selection is made, two more selection boxes appear, the first asking the user to select the river theme, and the second asking for the elevation theme.

In importing the FLDWAV output, M2M opens the output file, searches for the section entitled "Profile of Crests and Times", and, first of all, reads the column headings to determine whether the output distance units are in kilometers or miles. Then, line by line until the end of the output section, M2M parses the output data, determining, for

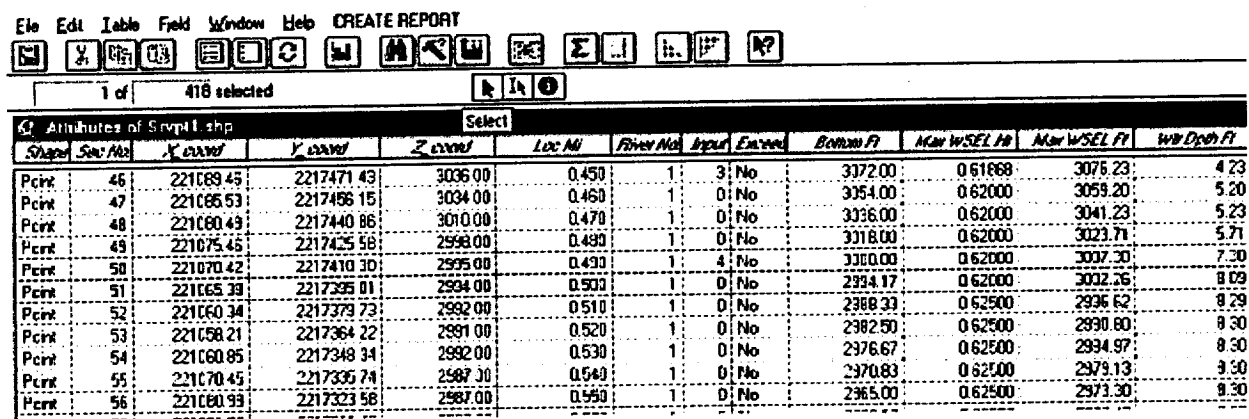
each output point, its geographic coordinates in the manner discussed in the **Import FLDWAV Input** section above. At the same time M2M calculates the water depth at the output point by subtracting the channel bottom value from the maximum water surface elevation value (MAX WSEL – BOTTOM).

When survey point coordinates are known, green graphic representations of the points plot on the Workspace display, and the survey point data appear in the **Survey Points** list box of the **Create Survey Points Theme** dialog (Figure 12).

Create Theme: When the user clicks the **Create Theme** button, the data in the **Survey Points** list box and the green graphic points on the display are converted into a survey points theme, and the **Create Survey Points** dialog closes. The new theme, entitled **Srvptx.shp**, appears in the Workspace, with the points redrawn in magenta. This theme's data can be examined using the **SURVEY POINTS / SHOW SURVEY POINTS DATA** menu option, discussed in following paragraphs, and can be edited using the **Import Existing Theme** button, discussed above. The theme's underlying files are stored on disk, in the Workspace's working directory.

Cancel: When the user clicks **Cancel**, any green graphic points in the Workspace display are erased, data in the **Survey Points** list box are discarded, and the **Create Survey Points** dialog closes.


SURVEY POINTS / SHOW SURVEY POINTS DATA: Activate a survey points theme and then select this menu option. The active theme's data is then displayed in a table, like the one in Figure 26. The theme's data include the **X_**, **Y_**, and **Z_coords** as well as all the data from the "Profile of Crests and Times" section of the associated FLDWAV output.




Shape	Srvptx	X_coord	Y_coord	Z_coord	Loc_Mi	River_Mi	Input	Export	Bottom_Ft	Max_WSEL_Ft	Max_WSEL_Ft	Wtr_Depth_Ft
Point	46	221089.45	2217471.43	3036.00	0.450	1	3	No	3172.00	0.61868	3075.23	4.23
Point	47	221086.53	2217486.15	3034.00	0.460	1	0	No	3054.00	0.62000	3059.20	5.20
Point	48	221080.49	2217440.86	3010.00	0.470	1	0	No	3036.00	0.62000	3041.23	5.23
Point	49	221075.45	2217425.58	2998.00	0.480	1	0	No	3018.00	0.62000	3023.71	5.71
Point	50	221070.42	2217410.30	2995.00	0.490	1	4	No	3000.00	0.62000	3007.30	7.30
Point	51	221065.39	2217395.01	2994.00	0.500	1	0	No	2994.17	0.62000	3002.26	8.09
Point	52	221060.34	2217379.73	2992.00	0.510	1	0	No	2988.33	0.62500	2996.62	8.29
Point	53	221058.21	2217364.22	2991.00	0.520	1	0	No	2982.50	0.62500	2990.80	8.30
Point	54	221060.85	2217348.34	2992.00	0.530	1	0	No	2976.67	0.62500	2994.97	8.30
Point	55	221070.45	2217335.74	2987.00	0.540	1	0	No	2970.83	0.62500	2979.13	8.30
Point	56	221080.99	2217323.58	2987.00	0.550	1	0	No	2965.00	0.62500	2973.30	8.30

Figure 26: Table of Survey Points Data

When the table of survey points data is active (the title bar is blue) then the M2M table menu appears across the top of the ArcView project. This table menu bar has the standard ArcView table menus on the left, and the M2M menu, **CREATE REPORT**, on the right (see top of Figure 26).

If the user clicks on a line of data with the **Select** tool , the line is highlighted (as in the Figure 26 above) and the associated survey point is highlighted in the Workspace

display. To highlight multiple lines at the same time, the user holds down the Shift key while clicking. To unhighlight the data, use the **Select None** tool .

CREATE REPORT: This menu is available whenever a survey points data table is active. The options included in this menu allow the user to transfer the survey points data to other media, including printed report and Excel spreadsheet. The menu options are discussed below.

CREATE REPORT / PRINT DATA: This menu option is a link to ArcView's Report Writer extension, bringing up a **Create a report** dialog of eight report formats from which to choose. Depending on the software available on the host computer, one or more of these format options may be disabled. The option that is always available is the "Quick Report", whose formatting dialog is displayed in Figure 27. The **Quick Reports** dialog allows the user to select, among other things, the data fields to be included in the printed report.

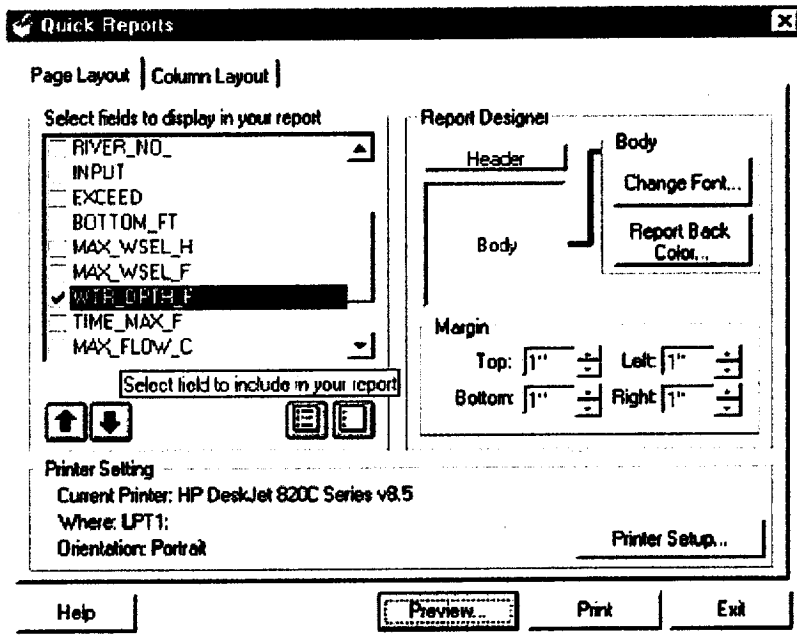


Figure 27: "Quick Report" Print Option

CREATE REPORT / EXPORT DATA TO EXCEL:

This menu option brings up a simple **Export to Excel** dialog, pictured in Figure 28. The user must supply the path to the Excel spreadsheet executable, typically located in C:\Program Files\Microsoft Office\Office\Excel.exe. When the **Excel Location** is filled in, the user clicks the **Export to Excel** button, and all the survey points data are transferred to an Excel spreadsheet which appears on the screen.

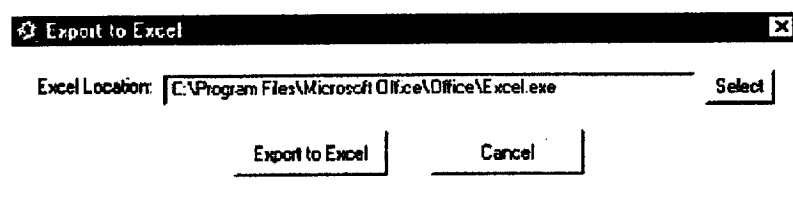


Figure 28: Export Survey Point Data to Excel

The first line of the USGS DEM file contains a record of DEM characteristics, including the elevation units. The user can open the USGS DEM file in a text editor, and examine the data, if necessary. This first line of data is known as the DEM's "A" Record, and a full description of this record can be found in Appendix 2-A of the document "Standards for Digital Elevation Models", displayed in Acrobat format at the site <http://rockyweb.cr.usgs.gov/nmpstds/acrodcs/dem/2DEM0198.PDF>.

Figure 30 shows the first line of the file 43.dem from M2M's Samples directory. Several of the DEM characteristics are identified in red. The elevation measure is a coded entry, where 1 = feet and 2 = meters.

The code translations for the remainder of the "A" Record descriptors are given at the website noted above. For the DEM in Figure 30, projection is UTM, Zone 5, distance measure in meters, elevation in feet, x, y, and z spatial resolution is 10, 10, 1 (10m by 10m cell size, with 1ft elevation increments), and horizontal datum is NAD 83.

River Shape Theme: This combo box lists all polyline shape themes present in the Workspace. The user selects the one representing the river, or flood path, leading from the dam to the final survey point of the study area. The section **Create the Flood Path Theme**, in the **Inundation Mapping Process Walk-Through**, gives instructions on creating this flood path.

Survey Points Output Theme: To populate this combo box, M2M searches all point shape themes for fields showing x- and y-coordinates and water depth. The user selects the one representing the FLDWAV output that he wishes to map. Creation of a survey points theme from FLDWAV output is discussed in the **SURVEY POINTS / CREATE/EDIT SURVEY POINTS** section in this portion of the guide.

Generate Initial Flooded River Grid: Clicking this button starts the process of creating a grid of water depths along the river, interpolating the depths for the pixels in between the output points of the survey points theme (see Figure 14). The theme generated by this process is named **Flooded River from Srvptx.shp**. When this flooded river grid theme appears in the Workspace, the user is ready to generate an inundation map.

Generate Flood Water Depth Grid (control panel): This grouping of controls is used to generate the inundation map. The inundation mapping process is iterative, and this section of the **Generate Inundation Map** dialog is used again and again, to expand the inundation map.

Flooded River Grid Theme: This combo box lists all grid themes present in the Workspace. The user selects the one representing the current state of the flooded river. If this is the beginning of the inundation mapping process, the flooded river grid would be the initial flooded river grid; the one named **Flooded River from Srvptx.shp**. If the inundation mapping process is already in progress, the flooded river grid would be the most recent flood water depth grid produced, with a name like **floodx**.

Number of Iterations: The production of the inundation map is done in layers of pixels, expanding out from the initial flooded river grid like the skins of an onion. The **Number of Iterations** is defaulted to 10, but the user can increase or decrease this number. If this number is set too high, the user will get the ArcView message, “No Free Channels”. The ArcView help has the following to say about this error message: *“In most cases, channels refers to the number of file handles available for the system to use, as statically declared memory. The number of file descriptors is set in your CONFIG.DOS (see its FILES line). By increasing the descriptors, you can increase the number of channels as well. If you alter the number of descriptors, you will need to reboot your machine for the new value to take affect.”*

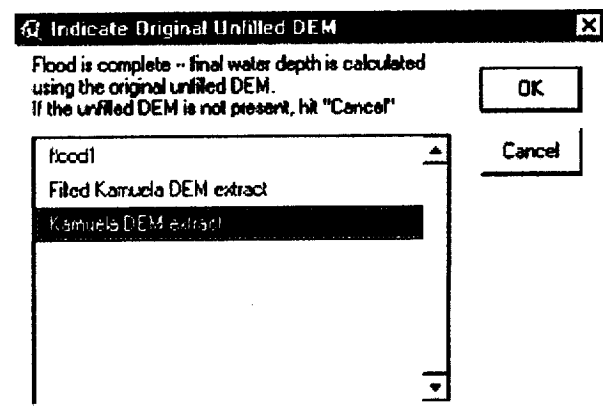


Figure 31: Flood Is Complete

If the inundation map is completed during the number of iterations specified, a message box will appear (see Figure 31) asking for the original unfilled DEM, so that it can be used for the final flood water depth calculations. If the unfilled DEM is not in the Workspace, the user can click **Cancel**, and the filled DEM is used instead.

Current Iteration: This read-only text box displays the current iteration of the flood mapping process. When the process finishes, this box is blanked out.

If the user wants to stop the inundation mapping process prematurely, he can use the **Stop** button in the lower right corner of the M2M project window (see Figure 32). This button is only present while the process is running.

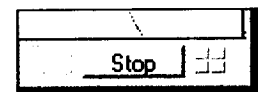


Figure 32: Stop the Process

Generate Flood Water Depth Grid: When the user clicks this button, the process of creating an inundation map begins (or continues, depending on the input flooded river grid theme).

Dismiss: Clicking this button closes the dialog. This button should not be clicked while the mapping algorithm is executing. See Figure 32 for the method of interrupting the process.

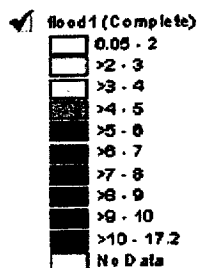
INUNDATION MAP / RECLASSIFY FLOOD LEGEND: This menu option brings up the **Reclassify Flood Legend** dialog, pictured in Figure 33a, which enables the user to regroup the flood waters in different ways. The paragraphs below describe the different controls.



Figure 33a: Reclassify Flood Legend Dialog

Figure 33b: Reclassified Flood Grid

Figure 33c: Reclassified Legend



Flood Theme: The user selects the flood grid from the **Flood Theme** combo box.

Min: Flood water depths of **Min** and below are grouped together to depict non-critical flood depths. This value can be integer or float.

Color for Min value and below: Colors available for the “Min value and below” flood waters are green, white, or transparent (as in Figures 33a-c).


Max: Flood water depths greater than **Max** are grouped together to depict critical flood depths. This value can be integer or float.


Color for values greater than Max: Colors available for the “greater than **Max** value” flood waters are black, yellow, and red (as in Figures 33a-c).

Interval Size: This value regulates the size of the flood water groupings for all water depths in between the **Min** and **Max** values. This value can be integer or float.


Reclassify Legend: Clicking this button causes the selected **Flood Theme** to be redrawn using the newly reclassified legend.


Dismiss: Clicking **Dismiss** causes the dialog to close.

Return To Main : The **Return To Main** button closes the current Workspace and brings the user back to M2M's Main Window (Figure 1). There is a similar button on the Project Window menu bar (see Figure 15) to help lost users find their way home.

Water Path : The **Water Path** tool traces the path of a drop of water across an elevation grid. When using this tool, the active theme in the Workspace should be a filled DEM elevation grid. The user clicks on the tool, the cursor turns into a bullseye, and, with this bullseye, the user clicks onto a point on the elevation grid. The path of water originating at that point is traced in bright green graphics across the DEM.

If a dam is not located on a river, as in the example in Figure 7a, then the **Water Path** tool can be used to determine the direction of water flow from the dam break to the river (see the resulting green line in Figure 7b), as a preliminary step in the creation of the flood path theme.

To remove the green graphic left by this tool, select the graphic using the **Pointer**  tool, then hit the keyboard Delete key.

Profile Extractor : The **Profile Extractor** tool graphs cross-sections of terrain extracted from DEMs or contour themes. This tool can be a useful aid in selecting survey point locations, and in compiling input data for FLDWAV, or just in observing the lay of the land.

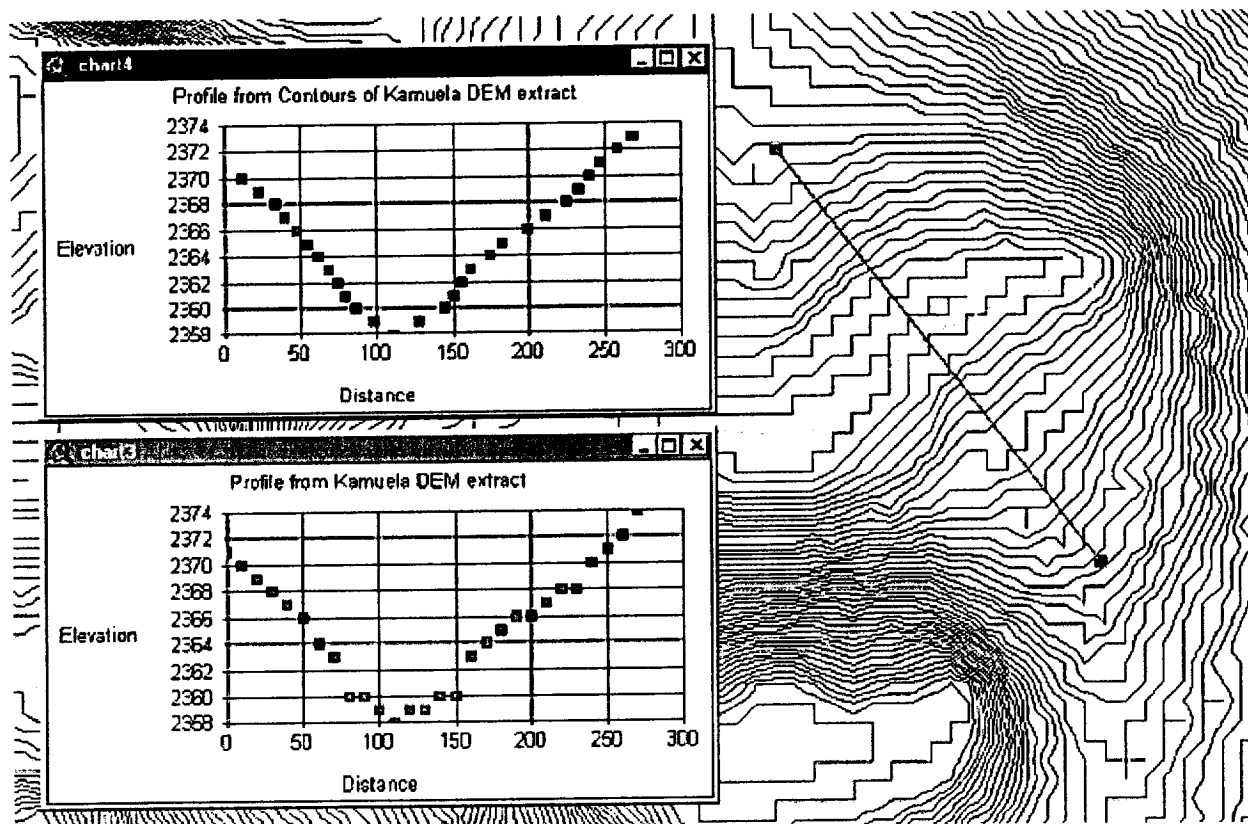




Figure 34: Graphs from Profile Extractor Tool


To use the **Profile Extractor** tool, the user activates either a DEM theme or a contour theme (by clicking once on its legend) and then clicks on the  icon. The cursor turns into a crosshairs cursor, and with this cursor the user draws a straight across the selected terrain (see red line in Figure 34). The result is a graph of the terrain elevation versus the distance from the beginning of the line. The units of measure for elevation and distance are whatever units are in use in the DEM (see Figure 30 to help determine units of measure in DEM). To view the data at a point on the graph, the user clicks on the point with the **Identify**  tool.

If the terrain is a contour theme, the resulting graph (see the top graph in Figure 34) displays a point each time the user's line crosses a contour line. Contour themes are produced from DEMs using the ArcView **Surface/Create Contours...** menu option. The background of Figure 34 shows a contour theme.


If the terrain is a DEM, the tool determines the DEM cell size *cellsz*, and then extracts elevation data from the DEM every *cellsz* interval from the beginning of the user's line (see resulting graph at bottom of Figure 34).

Both terrain types produce similar results (the graphs in Figure 34 were produced from the same line), but using the contour theme is more useful in close-up situations (like measuring a stream cross-section) and using the DEM theme is more useful for large expanses (especially since the graphs are limited to 100 points).

If the user draws a line that would result in more than 100 points, a message box pops up saying that the graphing capability has been exceeded. In this case, the user should draw a shorter line, use a contour theme with contours further apart, or switch from a contour theme to a DEM.

To get rid of the red graphic line left by the tool, the user should select the line (if it is not already selected) using the  tool, then hit the keyboard Delete key. If there are lots of residual graphics, the user can select them using the ArcView menu option **Edit/Select All Graphics**, and then delete them all at once.

If the charts disappear behind the Workspace, the user can recall them using the **WORKSPACE / VIEW CHARTS** option. To delete the charts, the user should use the **WORKSPACE / DELETE CHARTS** option.

Grid Cropping  Tool: The **Grid Cropping Tool** extracts a rectangular section from a larger grid to create a smaller grid theme. M2M provides this tool so that users can limit their DEMs to the immediate study area, thereby giving M2M the smallest possible grid on which to perform its time consuming inundation operations.

To use this tool, the user activates a DEM theme, then clicks the **Grid Cropping Tool** icon. With the resulting crosshairs cursor, the user draws the rectangular boundaries of the new grid. The new DEM extract appears in the Workspace in graduated shades of orange.

Appendix A

Inundation Mapping Technical Documentation

The following paragraphs describe the evolution of the inundation mapping methodology that is currently included with the prototype M2M Dam Failure Inundation Mapping project.

The method begins with an ArcView theme of point shapes, depicting the FLDWAV model output of water depth at various points along the river following the dam break. In Figure 1, these points are the magenta dots. The water depths at these points are then used to interpolate water depth for each pixel comprising the river shape, resulting in an initial river water-depth grid (visible beneath the magenta dots on Figure 1).

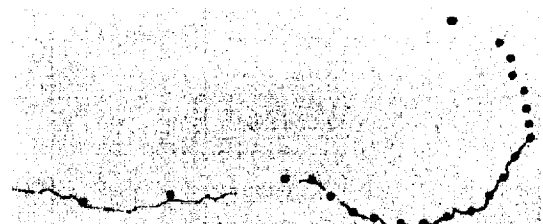


Figure 1: River Water-Depth Grid

In preparation for the following steps, a depressionless digital elevation map (DEM) of the study area is prepared. M2M provides the function for filling the depressions in a DEM.

First Attempt. In researching flood inundation mapping on the internet, we came upon an NWS project with similar goals as ours, and we entered into correspondence with one of the NWS analysts. Although the NWS project primarily used C, Motif, and Informix, the analyst provided us with a description of their methodology (see Figure 3) that provided us with important insight. The included extract from this correspondence describes an "Onion Skin" approach, which we implemented within ArcView as our first serious attempt at inundation mapping, the result of which is shown in Figure 2.



Figure 2: First Attempt Flood Map

Following the NWS methodology, the elevations of DEM pixels are compared to adjacent flooded pixels (if there are any). If the DEM pixel is lower than the closest adjacent flooded pixel, the DEM pixel is assumed to be flooded, and is assigned the elevation of the adjacent flooded cell. Iteration upon iteration is calculated, layering pixels upon the flood like layers of skin on an onion.

> 4) The next step is a bit complicated. We could have generated a flood
 > surface from the river elevation points and intersected it with the
 > conditioned DEM to indicate area of flooding. This approach has at
 > least 2 problems: a) if the river system isn't reasonably straight
 > or involves more than one channel there is a chance the flood
 > surface will indicate overland flow where it doesn't exist and b)
 > flooding can be indicated on the back side of levees and other
 > control structures and low areas outside of the flood plain. In our
 > approach there is little if any chance of that occurring (it also
 > lets us model breaks/failures in levee systems). Our approach is
 > difficult to describe. Think of it as an onion skin, we build up our
 > flood map one layer of pixels at a time on either side of each
 > thalweg in the mapping region. This is a recursive process. In the
 > first recursion we compare thalweg DEM elevations against river
 > elevations. If the river elevation is higher than the DEM we know
 > the area is flooded and the depth of flooding. In the 2nd recursion
 > we look at the DEM pixels immediately next to the thalweg. For each
 > of these pixels we find the closest flooded pixel (if there is one)
 > and its river elevation. If the DEM is lower than the river
 > elevation we indicate that pixel as being flooded and we note the
 > nearest elevation of the river. The 3rd and subsequent recursions
 > are like the 2nd. The elevations of DEM cells adjacent to flooded
 > cells are compared to the nearest river elevations. If the DEM is
 > lower than the closest adjacent flooded cell, that pixel is assumed to be flooded.
 > Recursion after recursion is processed until no more flooded cells
 > are found. The trick is to not only map whether or not the pixel is
 > flooded, but to also carry along the NEAREST river elevation as you
 > build up these layers. This method will a) prevent you from mapping
 > floods where there is no clear path back to the thalweg, b) will map
 > flooding behind islands within the flood plain, c) put water behind
 > flood control structures but only if there is a break in the
 > structure. and d) is consistent with the mechanics of flooding
 > (ie, will not generate overland flooding where it does not exist).
 > BUT, this method assumes that the surface of the river is of constant
 > elevation perpendicular to the thalweg. The model used to generate
 > our input river elevation data met this assumption. The mapping
 > method can be modified to deal with the exceptions to this assumption.

> Andrew Rost
 > National Operational Hydrologic Remote Sensing Center
 > Office of Hydrology, National Weather Service, NOAA
 > 1735 Lake Dr. West, Chanhassen, MN 55317-8582
 > Voice: (612)361-6610 x 234
 > Fax: (612)361-6634
 > arost@nohrrsc.nws.gov
 > <http://www.nohrrsc.nws.gov>

Figure 3. Correspondence With NWS Analyst

The flood map of Figure 2 is shown after 200 iterations of “onion skin” layering. This method didn’t work well for our test scenario because of the steep cliffs next to our river, violating the “constant elevation perpendicular to the thalweg” assumption of the NWS methodology (see the “BUT” caveat near the end of the Figure 3 correspondence).

First Attempt required further modification, and this led to Mod 1.

Mod 1. In the first modification to the NWS methodology, the water depth of a newly flooded pixel was not allowed to exceed the water depth of the nearest flooded river pixel, so that instead of carrying the nearest river pixel elevation to the next flooded pixel (as in Method 2), the river water depth was the value carried. Prior to implementing this modification, water spilling over a cliff at 3000 ft would flood the adjacent 2900 ft pixel to a depth of 100 ft.

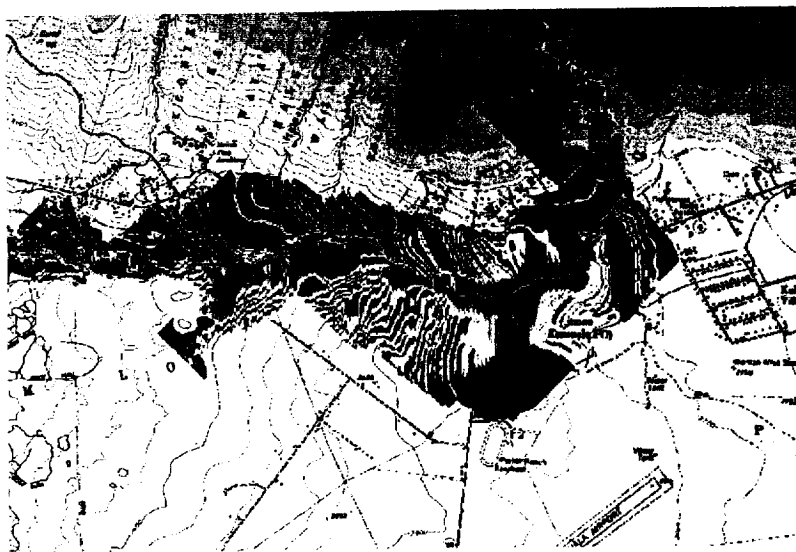


Figure 4: Mod 1 Flood Map

Figure 4 shows the Mod 1 flood map after 100 iterations. There was still an evident water depth problem, visible in the dark blue patch at the bottom of the flood. It does not make sense for flood water to deepen again, after having gotten shallower, when using a depressionless DEM.

Mod 2. In the second modification to the NWS methodology, the water depth of a newly flooded pixel was not allowed to exceed the water depth of the adjacent flooded pixel. Following this method, shallow water does not get deeper again.

Figure 5 shows the flood map after 200 iterations of Mod 2 methodology.

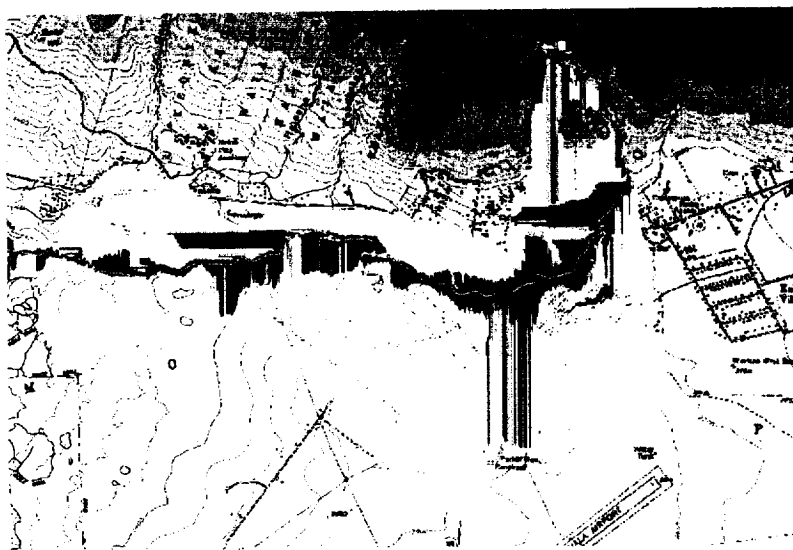


Figure 5: Mod 2 Flood Map

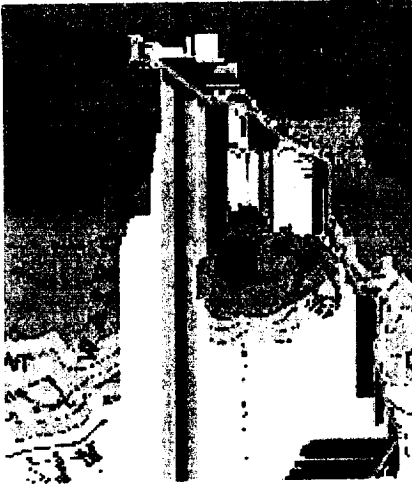


Figure 6: CloseUp in Mod 2

There was still an obvious problem, this one dealing with non-flooded pixels. In our interpretation of the NWS methodology, a pixel that was once marked as “not flooded” remained forever as “not flooded”. The “close up” picture in Figure 6 shows water coming together from two sides in a flooded area. The shallower water coming from the right failed to flood a line of pixels, which should have been flooded later by the waters coming from the left. This was corrected later in Mod 3.

Mod 3. Mod 3 corrects the non-flooded pixels problem: Pixels not flooded on the first attempt can still be flooded later by waters approaching from another direction.

Figure 7 shows 220 iterations of Mod 3. In this figure, the light color blue is the shallowest flood water, ranging from 0.05 feet to 0.567 feet, so although the flood looks extensive, it is very shallow in places.

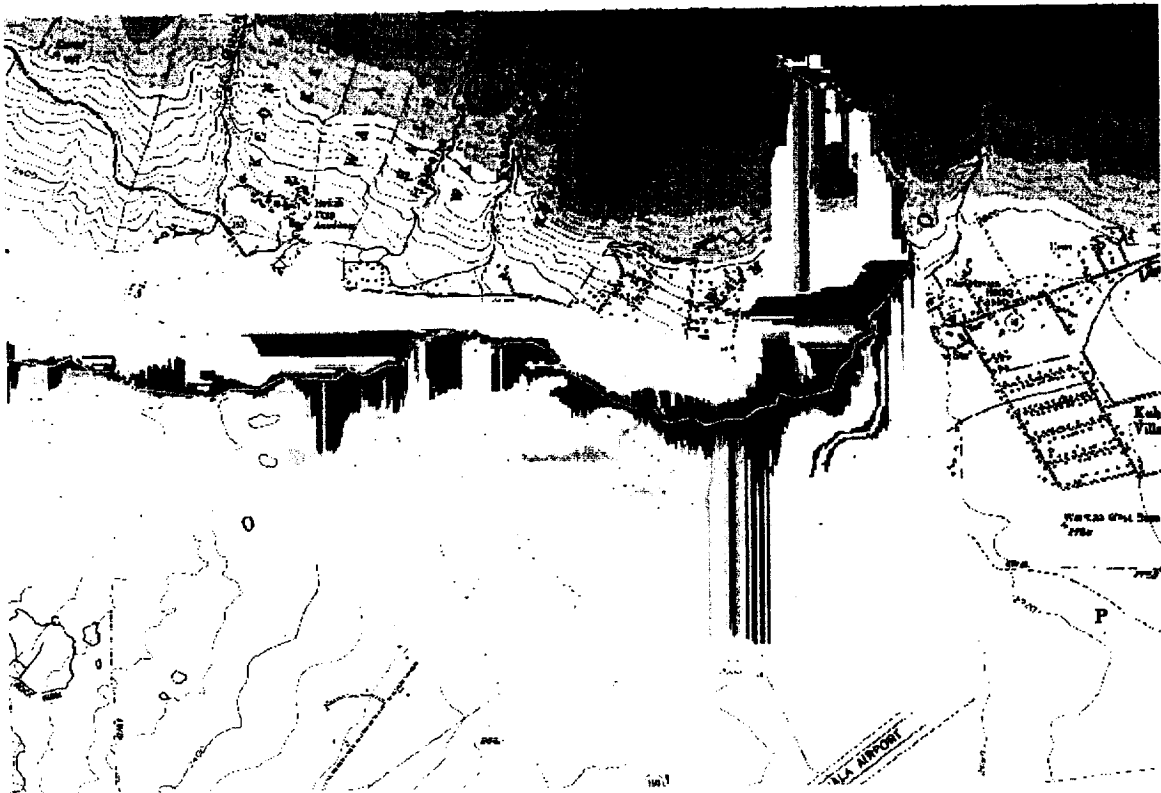


Figure 7: Mod 3 Flood Map

Latest Mod. In the latest modification to the evolving methodology, flooding from one cell to an adjacent cell is weighted by the elevation of the cell. Because each pixel has up to four adjacent pixels that have not yet been evaluated, this weighting makes it more likely for a given pixel to flood an adjacent pixel of lower elevation, and to have the pixel of higher elevation be flooded by one of even higher elevation.

The flood map of Figure 8 is shown after approximately 100 iterations of the latest “onion skin” layering methodology.



Figure 8: Inundation Map Using Prototype Methodology

Appendix B

FLDWAV Tips

Developing FLDWAV Input

The **10m DEM of the study area** should include the dam, the stream downstream of the dam, and the area which will potentially be flooded. The larger the DEM, the longer it will take to generate the inundation maps, so limit the DEM to the immediate study area by using the M2M Grid Cropping Tool.

Use a **digitized version of the standard topographic maps** (USGS 7.5 minute quadrangle) in conjunction with the DEM, to facilitate identification of landmarks. Note that the DEM and topographic map must be in the same UTM projection and same datum (NAD83 vice NAD27). For Big Island sites, one must be aware that some maps are projected into UTM zone 4, and some in zone 5.

If the dam is off-stream, a **site visit** may be necessary to determine which side of the dam is most likely to fail, and to determine the immediate flow path taken by the floodwaters. From a topographic map it is not always obvious which direction the flow will take, as in the case of a circular dam on a topographic saddle. During the site visit it is also worthwhile to take crude measurements (paced and eyeballed) of the channel cross-sections at readily- (and legally-) accessible sections of the channel downstream of the dam. Site visits are also helpful in assessing the type and condition of vegetation and this will determine Manning's n values.

The minimum required information about the dam is the dam type (earthen vs concrete arch), the **hydraulic height of the dam**, and **the surface area** when at maximum capacity. To refine the estimate of the flood, one should have cross-sectional maps of the reservoir, which can be obtained from DLNR.

Determine **where to put cross-sections** for the FLDWAV input. A cross section is needed on the dam at the point of failure (this should be the upstream end of the stream theme), and 0.01 miles downstream of the dam. The distance step of the model is 0.01 miles, so ideally the cross-sections should be placed at distances of even hundredths of a mile (1.30, not 1.32 or 1.29). Cross sections are also needed wherever there is a significant change in slope, cross-section shape, or roughness. Special considerations are needed where there is a change in cross-section shape or roughness, because FLDWAV interpolates these values between cross sections. Thus, *two* cross sections may be needed to accommodate a change in roughness or cross section. Placing a cross-section at critical points (where highway crosses the stream) is optional. An extra cross-section is also needed when the flood flows out of a canyon into a broad floodplain. Place this cross section about 0.25 miles downstream of the bottom of the canyon and designate a good portion of the floodplain as "inactive" (flow is to the sides, not downstream). The next cross-section downstream should have "floodplains" (slower, shallower downstream flow on the margins), but no "inactive channel. FLDWAV contains provisions for hydraulic modeling of flow through bridges. Bridge

modeling is tricky and best avoided. Modeling the bridge as a constriction in the channel is a good solution.

Develop cross-sections from the DEM: Your ultimate goal is to develop elevation-width pairs that define the cross sections. FLDWAV requires the same number of pairs for each cross-section. The maximum depth of the cross sections should be about one-half the hydraulic height of the dam.

How to measure cross sections: In your M2M Workspace, make sure that the points depicting cross-section locations are displayed. Display the DEM but not the topographic overlay. Use the **Surface/Create Contours...** menu option to create 4 ft topographic contours from the DEM. Zoom in on the cross section area and, with M2M's **Profile Extractor** tool, draw a line perpendicular to the channel. The line should touch where a contour crosses the channel. Using the data points on the resulting profile graph, calculate the distance between where a single contour crosses the line. For example, if the elevation of the stream (at the line) is 1000 ft, calculate the distance between the two locations where the 1004 ft contour crosses the line. This is the width at an elevation of 1004 ft (depth of 4 ft). Repeat for each contour up to the maximum desired depth. If your DEM is a UTM projection, the distances along the graph's x axis are in *meters*.

Where exactly to measure: Your goal is to obtain *representative* cross-sections in the general vicinity of the cross section. If you like, you can measure several cross-sections and then average. Remember that FLDWAV interpolates the cross-sectional shape in between actual cross-sections. This interpolation also applies to the inactive channel and the floodplains. It is suggested that you take measurements of *depth*-width pairs, and later convert this to *elevation*-width pairs based on the stream elevation at the actual cross section point.

Flow not confined to valley: You may reach a contour that does not cross the line twice. This means that at this elevation the flood is no longer confined by a valley and is spilling out into a different drainage. In effect, the cross-section width is infinite and flow is no longer one dimensional. Initially, list "infinite" as the cross-section width. Later, specify the "active" width for this depth as something slightly bigger than the width of the next lower contour, and specify an "inactive" width of ~10,000 ft.

Known Bugs in FLDINP

FLDINP has problems related to reading and writing FLDWAV input files: FLDINP has difficulty reading some files that can be read perfectly well by FLDWAV. After some point in the file, all values that should be read in end up with zero values instead. Error messages will alert you to this problem ("warning -1 is less than 0"; "warning - cannot set elevation on conveyances"). Sometimes the FLDINP will not be able to read any data at all (but if you chop off problematic data at the end of the file it may be able to cope with the data at the beginning of the file).

When writing FLDWAV files, FLDINP puts four extraneous lines after the upstream boundary hydrograph. FLDWAV will run the resulting file only if one deletes the four

extraneous lines with a text editor. However, having done so, FLDINP will not be able to re-read the file. If you try to put the four extraneous lines back in order to make FLDINP happy, FLDINP will still be unable to read the file.

When writing files, FLDINP sometimes puts two extraneous lines before the expansion coefficients, but for some reason these extraneous lines are not a problem for FLDINP.

FLDINP has problems related to sinuosity coefficients: While FLDINP recognizes that sinuosity coefficients must be specified when the floodplain option is exercised, it completely forgets about sinuosity coefficients when reading or writing files. This prevents the Manning's n values from being read (if there are floodplains.)

In a related matter, FLDINP seems incapable of reading in FLDWAV input decks that contain floodplain info. It is capable, however, of *writing* FLDWAV input decks containing floodplain info, with the notable exception that it will forget to put in the sinuosity coefficients. This problem can be overcome by manually inserting sinuosity coefficients between the end of the cross-section data and the expansion coefficients. Simply enter a bunch of ones using notepad, where the number of ones is equal to the number of data pairs in the cross-sections times the number of reaches (number of cross-sections minus one).

Problems with getting data that is input to "take": One must be careful entering data, as simply typing a number and hitting enter is not always sufficient. This problem has been observed at the last row of the table with the cross section topography data. Try using the up or across arrows to finish entering data into the last row. Efforts to change a cross-section from a section that has a new Manning's n to one that was not were unsuccessful. No matter how many times one deleted the little "check" it would reappear mysteriously.

Hints for preparing input files acceptable to FLDINP:

1. Do not use tabs to separate the data fields. If you do, FLDINP will fail to read in all the data after the tab.
2. Do not separate the data fields by too many zeros. However, in data group 50 (labels for plots), the number should be right justified in a column 10 characters wide. (The new input files have omitted the plots and data group 50.)
3. The comment lines (in between lines with data values) should not be too long.

FLDWAV Idiosyncrasies

Initial and boundary conditions: The input file requires that an input hydrograph be specified as the upper boundary condition. However, since the dam break is the *actual* upper boundary condition, the program ignores whatever values are specified in the input hydrograph. If one wants to specify an initial discharge in the stream, one must set the dam's turbine outflow to the desired value. Curiously, the dam does not break unless the dam's turbine outflow is greater than zero.

Instability is a BIG problem: Abrupt change in slope can produce instability. Try downstream routing of a steady flow equal to the flood peak, and look for oscillations in the flood elevation (which should vary smoothly in time and distance). Fix by putting in more cross-sections to allow for a more gradual change in slope.

Bridges: Advice from the FLDWAV user group indicates that bridges are problematic, and suggests that users represent bridges using a channel constriction.

Interpretation of M2M Inundation Maps

At a given location the flood waters will rise rapidly and then fall rapidly as the flood moves downstream. Thus, at any given instant in time, the flood will be deep only in certain areas. The inundation maps show the maximum flood depth that is expected for each area. The *time* of maximum flooding is, of course, different in different parts of the map. The inundation maps do *not* show the flood at a given instant in time.

